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EDITED BY P. F. ROWELL, SECRETARY.

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CORRIGENDA.

p. 82, 1st col., line 11: For "of" *read* "or".

p. 179, 2nd col., par. 3 (*b*): For "stress" *read* "bending moment", *delete* the words "at 1 ft.", and for "cwt." *read* "foot-cwt.".

p. 179, 2nd col., par. 3 (*c*): *Delete* the words "at 1 ft.", and for "cwt." *read* "foot-cwt.".

p. 179, 2nd col., line 41: For "1-ft. breaking stress acting on the pole" *read* "bending moment at the ground line".

pp. 179–180, pars. II, III, and IV: For "stress" *read* "tension".

p. 180, 1st col., line 14: After "safety" *insert* "5", and *delete* the words "to which they are stressed".

p. 180, 1st col., line 15: For "Breaking stress of round insulator pins" *read* "Strength of insulator pins".

p. 198, last line: After "greater" *insert* "for the same temperature rise".

p. 200, Appendix VIII, 2nd col., line 2: For "0·000245" *read* "0·0000245".

p. 200, Appendix VIII, 2nd col., line 3: For "0·000136" *read* "0·0000136".

p. 274, 1st col. of Table, line 4: For "Vicars" *read* "Vickers".

p. 282, 1st col., lines 35–36: For "(V/2 R) A T is constant" *read* "(V/2 R) is constant".

p. 285, 1st col., line 26: For "$\bar{F} \sin \theta$" *read* "O B".

p. 286, 1st col., line 3: For "curve 11′" *read* "curve 11″".

p. 286, 2nd col., lines 14 and 24: For "curve 11″" *read* "curve 11′".

p. 429, 1st col., line 49: For "8·8" *read* "2·8".

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PRESSURE RISES.

Inaugural Address by WILLIAM DUDDELL, F.R.S., President.

(Address delivered 13th November, 1913.)

Gentlemen,—In the first place I wish to tender to you my thanks for having again honoured me by electing me to be your President for a second year. During my year of office I think I may say that the Institution has prospered. The number of members has considerably increased and work has been initiated in many new directions. The Research Committee is now in working order and researches have been started or are under consideration on Permanent Magnet Steels, Heating of Underground Cables, Insulating Oils, and Wireless Telegraphy. The catalogue of the lending library is being prepared and country members will very shortly be able to borrow books which they wish to consult. The first number of our fortnightly *Journal* will be issued next month, and through it I trust that the Council may be able to communicate with the members much more frequently than in the past. For this reason, it is unnecessary for me to-night to refer at any length to the present or future work of the Institution.

Last year in my address I tried to draw your attention to various sections of electrical science and industry which I thought were being to some extent neglected by the Institution. This year I propose to revert to a practice which was much more frequent in the early days of the Institution, namely, to give you a more technical address.

PRESSURE RISES.

The subject that I have chosen, namely, "Pressure Rises," is one which is of interest to a very large number of the members because these rises, which occur under very varied conditions, are a source of trouble not only to the station engineer but also to the users of electricity, as they may endanger apparatus which is connected to the mains.

I must at once disclaim that the material I am bringing forward is novel. What I am endeavouring to do is to collect together and illustrate experimentally before you to-night many of the well-known causes of pressure rises. Most of them are fully described in the literature on the subject, a list of which I give in an Appendix.

Under the heading of "Pressure Rises" I wish you to understand any rise in pressure above its normal value, but I propose to exclude from my address those accidental pressure rises which may occur should the speed of a generator become unduly high or should the current from a high-tension source get into a low-tension circuit, and to discuss those cases which take place during the apparently normal operation of the station or during faults on the mains.

The principal causes of pressure rises may be broadly divided into three classes:—

1. Resonance.
2. Switching.
3. Arcs and sparks.

1. Resonance.

An electric circuit which contains self-induction and capacity has, as is well known, a free period of its own, and electric oscillations may be produced in it provided that the resistance does not exceed a certain limit. If an alternator is connected to such a circuit, and if the period of the circuit is the same as the periodic time of the alternating E.M.F., then very violent oscillations may be set up in the circuit.

A limit to the strength of the oscillation is set by the apparent resistance of the circuit—by apparent resistance in this connection I mean a quantity which, when multiplied by the square of the current, gives the total losses in the circuit, including iron losses, eddy-current losses, etc., under the given conditions. For instance, if the apparent resistance R is comparatively small, then the voltage on the condenser or self-induction may rise to approximately $\omega L/R$ or $1/\omega C R$ times the E.M.F. of the alternator, where L is the self-induction, C the capacity, and $\omega = 2\pi f$, f being the frequency.

The most general case that occurs in practice is a long unloaded cable which is connected to an alternator. In this case the self-induction in the circuit is mainly the self-induction of the alternator itself. The capacity is the capacity of the cable, for unless the cable is very long it may be considered to act in just the same way as a condenser connected to the terminals of the alternator. In this very ordinary case resonance may be expected to take place if the period $1/f$ of the alternator is the same as the free period of the circuit. It may be thought that this case would occur very frequently, but it does not do so under normal working conditions.

It is easy to show * that in order to obtain resonance at any frequency the capacity current taken by the cable under normal voltage must be equal to the short-circuit current of the generator at normal excitation and at the frequency considered. No station could very well be run in this condition, as it means that the capacity current of the cables considerably exceeds the normal output of the generator. Although I have observed many cases of resonance of a 3rd, 5th, 7th, and higher harmonics, I have seldom seen cases of resonance of the fundamental—one of them will be referred to later.

With regard to the question of the upper harmonics, if the wave form of the alternator is not a pure sine wave but is of such a shape that it may be considered to consist of a fundamental sine wave on which is superposed an alternating current having three, five, seven, etc., times the supply frequency, then the case is somewhat different, for although the resonance of the fundamental cannot take place, a resonance of one of the upper harmonics is quite possible, since it is evident that as the frequency increases the capacity current taken by the cable increases and the short-circuit current for that frequency decreases, so that they rapidly approach one another. For instance, if the normal capacity of the cable were, say, $\frac{1}{9}$th of the short-circuit current of the alternator, then a resonance of the 3rd harmonic takes place if such a 3rd harmonic exists in the wave form. If the ratio were $\frac{1}{25}$, then the 5th harmonic might resonate. Now the ratio $\frac{1}{25}$ is quite a possible condition, for this roughly corresponds to the capacity current in the cables being about $\frac{1}{10}$th of the full-load current of the alternator, so that resonance of the 5th and higher harmonics may be expected in practice. Whether they are serious or not will largely depend upon the magnitude of these harmonics in the wave form of the alternator.

* Let E be the E.M.F. of the alternator,
f = frequency,
$\omega = 2\pi f$,
L = self-induction of the alternator,
C = capacity of the cable,
I_s = short-circuit current of the alternator determined in the usual way,
I = capacity current of the cable.

As a first approximation the resistance of the alternator and cable will be neglected. Then the short-circuit current of the alternator

$$= I_s = E / \text{Impedance} = E / \omega L.$$

The capacity current into the cable $= I_c = E\,\omega\,C$,

$$\therefore I_c / I_s = L\,\omega\,C\,\omega.$$

For resonance $1/f = 2\pi\sqrt{LC}$, or $LC = (1/2\pi f)^2 = 1/\omega^2$,

or—
$$L\,\omega\,C\,\omega = 1,$$

$$\therefore I_c / I_s = 1.$$

With modern alternators resonance seems to have practically disappeared in this country. In the early days I had some bad cases to investigate when resonance of one or other of the harmonics took place, which either caused failures or difficulties in regulating the voltage. With the modern machines the 3rd, 5th, and 7th harmonics are generally so small that there is no trouble from their resonating. Resonance of the higher harmonics is more likely to take place, but owing to the very much greater losses due to eddy currents, hysteresis, etc., the resonance of these higher harmonics does not in general attain a serious magnitude, especially if there is any load on the machine.

There is one point which it is necessary to bear in mind in connection with the possibility of resonance of one of the higher harmonics. It is quite true that in the ordinary three-phase systems the wave forms between the phases are practically free from the 3rd harmonic, but this is not necessarily true of the wave form between each of the terminals and the neutral point. Care must therefore be taken that the resonance of this harmonic does not occur. From this cause there might be quite a considerable potential difference between each of the cores of the cable and earth, whereas a record of the wave form taken between the cores might show nothing abnormal.

As a few examples of resonance of the higher harmonics observed in generating stations when the alternators were connected to feeders on open circuit, the following may be of interest.

Fig. 1 is the open-circuit wave of an old type of 400-kw. 2,000-volt alternator, and Fig. 2 is for the same machine connected through a 3 : 1 transformer to two of the feeders. The record which was taken on the high-tension side of the transformer shows a marked resonance of the 3rd harmonic, causing the potential-difference wave to fall almost to zero once during each half-period. The maximum volts are 10,140, or 1·60 times the R.M.S. value instead of 1·41 times for the sine wave. This is quite an exceptional case owing to the shape of the open-circuit wave and the large capacity of the cables in comparison with the size of the machine.

Fig. 3 shows the open-circuit wave of a more modern 500-kw. three-phase 6,600-volt generator, and Fig. 4 is for the same machine connected to two of the feeders. A resonance of the 13th harmonic has taken place and the maximum voltage has risen to 14,000, or 2·33 times the R.M.S. value.

As a further example of a resonance of a 13th harmonic, Figs. 5 and 6 show the potential-difference waves of a 1,500-kw. three-phase 6,600-volt alternator on open circuit, and with cables connected; the peak of the pressure curve in this case is 12,900 volts. Figs. 7 and 8 refer to the same case recorded between one terminal and earth.

The effect of the changes in speed on the wave form near a resonance is exemplified in Fig. 9, which shows the open-circuit wave of a 330-kw. 5,000-volt generator at normal speed, and in Fig. 10 for the same machine connected to four feeders. An increase of 8 per cent in the speed produces Fig. 11, and a reduction of 26 per cent Fig. 12.

The importance of the observation is that alternators should never have their speed run up or down when excited and connected to cables on open circuit, for fear

of passing through a possible resonance of an upper harmonic. In this connection I should like to draw attention to the case of switching off at the generating station a feeder connected at its far end to a running motor or rotary converter. When the switch opens, the cable is left

off together at the generating station, giving a very considerable rise in pressure on the feeder.

A similar case is shown in Fig. 14, in which a feeder supplying two motor-generators in a sub-station was disconnected from the busbars by tripping the oil switch. The

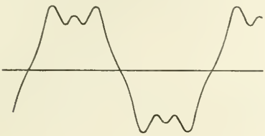

Fig. 1.

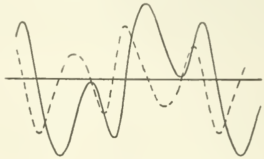

Fig. 2.

Fig. 3.

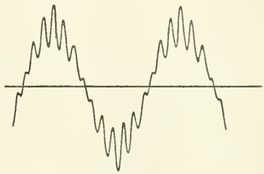

Fig. 4.

Fig. 5.

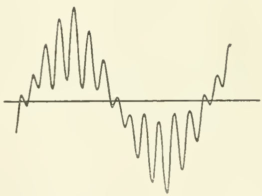

Fig. 6.

Fig. 7.

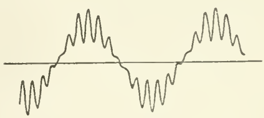

Fig. 8.

connected to the running motor or rotary converter which acts for a short time as a generator. As the machine slows down there is a considerable risk of a resonance, the more so as the self-induction of the motor or converter may be high enough to give a resonance even of the fundamental. An example of this effect is shown in Fig. 13, where a 500-kw. rotary converter and feeder have been switched

busbar pressure was 6,420 volts, but the maximum peaks on the record after the switch had opened are no less than 16,200 volts, due to a resonance of the 13th harmonic during the short time that the motor-generators were slowing down with the feeder on open circuit connected to them.

I have already mentioned that in order to get resonance

the cable system should be on open circuit. If the cable system has a number of transformers connected to it, the secondaries of which are on open circuit, the risk of resonance is still present because the magnetizing current taken by the high-tension side of modern step-down transformers is so small as hardly to affect the conditions. Directly there is any appreciable load on the system the risk of a serious resonance becomes very small and rapidly vanishes.

FIG. 9.

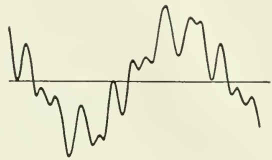

FIG. 10.

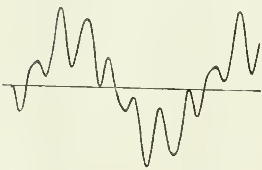

FIG. 11.

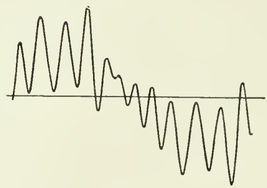

FIG. 12.

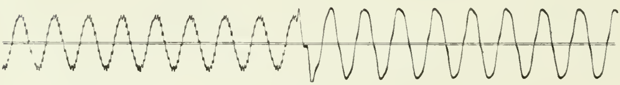

FIG. 13.

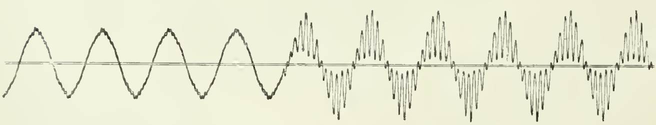

FIG 14.

It is necessary to point out that should, owing to any cause, the load be suddenly switched off the ends of long feeders so as to leave them unloaded and connected to the generator there is the probability of a pressure rise due to the combination of resonance, a rise in the speed of the generator, and interrupting the current, referred to below under "Switching."

There are certain special cases in which resonance of the fundamental may appear in unexpected ways. Perhaps the best method of illustrating this is by an actual example. A three-phase voltmeter transformer was connected to the busbars on the high-tension side by means of a fairly long length of cable. At the busbar ends of the cable were links which could be withdrawn in order to disconnect the transformer when required.

In this case it was found that if one of the links at, say, *b* (Fig. 15) were in place, the other two being open, a high voltage occurred between either of the other terminals and earth.

The neutral point of the generator was earthed, and each of the cables between the busbars and the instrument transformer had a capacity of about $\frac{1}{200}$ mfd. to earth. A circuit was thus formed through the closed link *b*, two coils of the transformer in series, and the capacity of the lead to earth, back to the neutral point. The self-induction of the two coils of the transformer in series was just about sufficient

to give a resonance when in series with the capacity of the cable to earth at the ordinary working frequency. The voltage, which should have been 4,620 (8,000 volts between phases) between *a* or *c* and earth was observed to be 10,100, or more than double the proper value. On disconnecting the pieces of cable between *a* and *c* and the transformer, the observed voltage on the open legs of the transformer fell to 4,700, practically normal value. Every time a voltmeter transformer was put in or out of circuit by withdrawing the link, the somewhat dangerous condition had to be passed through where one of the legs of the transformer was submitted to something like twice the normal pressure.

As another possible example take the case of a 100-kw. single-phase transformer supplied at 6,000 volts through a feeder one mile long and feeding into a distributing network. If the capacity of the feeder be taken as 0·25 mfd., the capacity current at 50 frequency will be just under $\frac{1}{2}$ ampere. The magnetizing current of the primary of this transformer may not differ much from $\frac{1}{2}$ ampere, and there is thus a possibility of a pressure rise should the feeder be disconnected at the generating station, leaving the transformer connected on the low-tension side transforming up and making the cable alive. If there was much magnetic leakage in the transformer this rise might be serious.

In two-phase or three-phase systems a number of combinations of the cables and transformers exist where, if a connection be opened, or during switching, the self-induction of the transformers may be in series with the capacities of the feeders, as pointed out by Steinmetz.

The resonances that may occur between the distributed self-induction and capacity of long cables causing rises of pressure at their ends, generally known as the "Ferranti effect," will be referred to later under "Switching" in order to avoid discussing the properties of long cables twice over.

Summing up, it may be said that resonance at the fundamental frequency is rare but very dangerous when it does occur.

Resonance of an upper harmonic is much more frequently observed, but with the good wave forms of modern turbo-alternators the amplitudes of the upper harmonics are so slight that their resonance does not generally produce any dangerous pressure rise.

2. Switching.

In switching apparatus in and out of circuit there are a certain number of cases in which the pressure may rise considerably above the normal irrespective of any arcing or sparking which may take place at the contacts. The best known is probably the ordinary case of opening an inductive circuit such as the field coil of a generator. If the rate at which the current is suppressed is sufficiently great, very high voltages can be produced, because the whole of the energy that is stored in the self-induction is set free, and must be either dissipated or stored in some available condenser. If an uncharged condenser is suddenly switched on to a generator, then in the general case the potential difference between the terminals of the condenser will rise not only to that of the generator but will overshoot the mark, and may, in the extreme case if there are no losses, reach twice the value. This is analogous to the ordinary case of the ballistic galvanometer in which, when the damping is small, the initial deflection on switching it into circuit is twice the steady deflection.

We have here, therefore, two fundamental cases where pressure rises may easily occur in practice, namely, when inductive circuits are suddenly opened or when condensers such as cables are suddenly charged. The simple case of

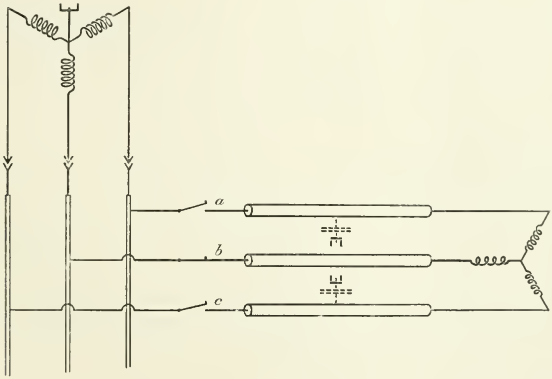

Fig. 15.

the inductive circuit is so well known that nothing more need be said about it except to point out that in the case of long feeders where the currents are large the energy stored in the self-induction of the feeders may be quite considerable; this is especially the case with continuous-current feeders.

As examples of the voltage rise when switching on a capacity, Fig. 16 shows the case of switching on and off 3 miles of cable on open circuit at 5,600 volts to a 1,000-kw. generator by means of an oil switch. The peak of the potential-difference curve is 14,500 volts, or about 2·6 times the R.M.S. value. The switching off of the cable gives no rise, the cable behaving like a simple concentrated condenser. The fine ripples on the curve are due to a high harmonic slightly resonated.

As another example, Fig. 17 shows the switching on and off of about 2 miles of cable by means of an air-break switch from a 5,000-volt generator of an old type which had not a very good wave form. At the moment of switching on the potential difference rose to 11,000 volts, or 2·2 times the R.M.S. value. It is to be noted that after the first contact at the switch the cable becomes charged by the oscillations. The switch then breaks contact and the charge in the cable leaks away through the oscillograph giving part of a discharge curve. About $\frac{1}{200}$th of a second later, while the cable is still partly charged, the switch makes contact again and the cable is re-charged, but this time in the reverse direction, from the following half of the wave form. The cable again becomes charged by the oscillations and finally settles down.

This effect of a switch not making perfect contact may lead to high pressures, because the upper limit to which the voltage on the condenser may swing is twice the difference of potential which is suddenly applied to it. For instance, if after the first contact the cable is left charged to a potential $+v$ and then contact is made again at the middle of the following half-period when the voltage is $-v$, the change of voltage applied to the condenser is $V + v$, and the first swing may amount to $2(V + v)$, or the voltage rise measured from the zero line, $2(V + v) - v$, say $2V + v$. In the worst case of $v = V$ we have a maximum of $3V$; or for a sine wave say 4·2 times the R.M.S. voltage.

I have already stated that no rise of potential takes place when switching off a condenser. If, however, sparking or vibration takes place at the contacts the effect just mentioned may occur. Fig. 17 is a good example where the cable was switched off from the machine, and it shows that while the cable was discharging after the first switching off the switch re-made contact again and re-charged the cable in the reverse direction. During the following discharge the switch again made contact and re-charged the cable, giving a pressure rise to 12,900 volts. The switch now finally breaks contact and the cable discharges with a tendency to a slow oscillation.

A bad case of vibration of the contacts of switching combined with a resonance is shown in Fig. 18, in which about 12 miles of feeder were switched on to the 400-kw. generator already mentioned (see Fig. 1). The cable was not quite discharged from previous experiments at the moment the switch made contact. The ordinary rise, but not a serious one, took place, and the switch remained closed for little over half a period. It then broke contact for approximately half a period; after which it re-made contact, giving a high rise in the reverse direction to 5,100 volts from a R.M.S. value of 2,000. During the next half-period the switch appears to have made good contact, but during the following one it has again been faulty in its contact. The moral is: Use a switch which closes quite clean without any chattering of its contacts, and switch on under oil, as the risk of a leading spark is thereby greatly decreased.

The smaller curve is the current flowing into the cable, which current it will be noticed has three times the fundamental frequency, owing to the fact that the conditions are practically the conditions of the resonance of the third harmonic of this machine already referred to. The results of a very large number of tests of switching on and

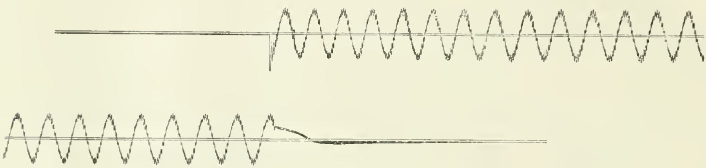

FIG. 16.

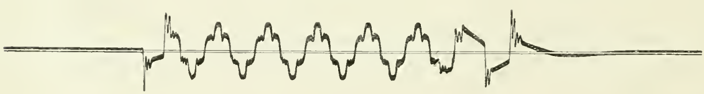

FIG. 17.

off cables on open circuit show that in general on switching on the cable, if no sparking takes place, the peak rarely exceeds twice the R.M.S. voltage, and that there is no rise on switching off. If, however, vibration of the contacts takes place or sparking, which will be referred to again later, then the peak may be more serious. If the switch is in good condition, however, the upper limit of the peak may, I think, be safely taken at three times the R.M.S. voltage.

As all cables and apparatus should at least be able to stand safely twice the working voltage for short periods, to switch on a cable should be quite safe provided no serious sparking takes place at the contacts.

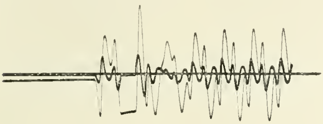

FIG. 18.

I have so far mentioned the cases of a capacity or a self-induction, *i.e.* a cable or a winding of a machine suddenly switched in or out of circuit. The next case is the switching in and out of a circuit which has both capacity and self-induction; in this case oscillations may be produced if the resistance is low enough. Assume for the moment that the capacity and self-induction are not distributed, that is to say, can each be considered to be situated at the point in the circuit, for instance at C and L in Figs. 19 and 20.

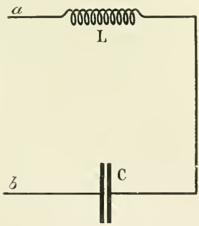

FIG. 19.

I will consider the effects according to whether a generator with a fixed voltage and with no self-induction or capacity is suddenly connected or disconnected between *a* and *b* (Fig. 19 or Fig. 20), *i.e.* the series or parallel arrangements. If the generator be suddenly switched in between *a* and *b* (Fig. 19) the charging current of the condenser will flow through the self-induction, storing energy in the magnetic field. At the moment when the condenser is fully charged, this stored energy will tend to maintain the flow of the current, and so overcharge the condenser, followed by the usual oscillations if the resistance is low enough. The upper limit of the voltage applied to the condenser, assuming that there are no arcs or sparks at the contacts, is twice the voltage impressed by the generator, but this is not attained in practice owing to numerous causes which dissipate the energy. The equation representing the voltage during the charging of the condenser is—

$$V_c = V_g (1 + \epsilon^{-at} \sin p t),$$

in which V_g is the E.M.F. of the generator and V_c the potential difference between the terminals of the condenser. The constant $a = R/2L$ is the log. decrement, and $p = 2\pi f$, where f is the frequency of the free oscillations in the circuit. This is the ordinary case of switching in a condenser, say a cable, and the limiting value of the pressure, *i.e.* when $p t = \pi/2$ (if no sparks or arcs occur, see later), is twice the machine voltage. It is to be noted that if the self-induction of the circuit could be made really nil there would be no rise; but this case is never obtained in practice.

On breaking the connection the condenser remains charged, and no pressure rise takes place. If the points

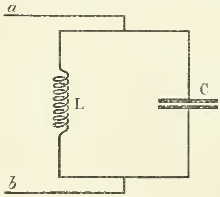

FIG. 20.

a and *b* be short-circuited the condenser will discharge through the self-induction, possibly with oscillations, but no rise will take place.

If the generator be suddenly switched without sparking on to the points *a* and *b* (Fig. 20), *i.e.* in parallel with the self-induction and the condenser, the condenser will be charged and the current will grow through the self-induction without any pressure rises owing to the assumed fixity of the voltage of the generator—as a generator with no self-induction does not exist the absolute fixity of the applied voltage is impossible, so some small initial rise may take place in practice. On switching off, on the assumption that no sparking or other form of dissipation of energy takes place, the whole of the energy stored in the magnetic field of the coil L is suddenly liberated, and must be transferred to and stored in the condenser. If the current through the self-induction be I, then the stored energy is $\frac{1}{2} L I^2$. If the voltage between the terminals of the condenser be V, the stored energy is $\frac{1}{2} C V^2$. These two quantities have to be equal if the energy is assumed to be transferred from the magnetic form to the electrostatic form without losses.

Hence—

$$\tfrac{1}{2} L I^2 = \tfrac{1}{2} C V^2, \text{ or } \frac{V}{I} = \sqrt{\frac{L}{C}}.$$

If the ratio L/C be known, then the limiting voltage corresponding to any current can at once be determined. For example, assume the self-induction of the generator to be 5 millihenries, and the capacity of two miles of cable to be ½ mfd., then $L/C = 10{,}000$ and $\sqrt{L/C} = 100$. Therefore if 1,000 amperes were suddenly interrupted at the end of the cable, a pressure of 100,000 volts might be produced. Owing to the spark at break, and the iron losses, leakage, etc., so high a voltage is not actually obtained.

The mathematical treatment of the general case of a long cable having distributed resistance, self-induction, capacity, and leakance, is somewhat difficult to follow in all its details. Dr. Kennelly's treatment of the subject by means of hyperbolic functions in a series of lectures given in this room enables a great many of the properties of these cables to be readily understood, and when the complete set of tables of the hyperbolic functions of imaginary quantities which Dr. Kennelly is preparing are finished, the labour of calculating any special case will be considerably reduced. For the present purpose of considering pressure rises most power-supply cables may be looked upon with sufficient accuracy as approximating to the two limiting cases of very short or very long cables. This leads to a great simplification of the discussion. For accurate prediction of the voltage drop and other properties of long lines, and also in telegraphy and telephony, these approximations are not permissible. A further simplification can be made if leakance be neglected, which is generally the case. Its effect if present will be to reduce rather than to increase the pressure rises.

Consider an infinitely long cable and let it be suddenly connected to an alternating-current generator at the moment when the potential difference is zero. As the potential difference increases at the generator end of the cable a current will flow into it charging up the condenser formed by the cable and earth, and this charge will travel along the cable with a certain velocity. Owing to the resistance and capacity of the cable the quantity of electricity flowing along it will become less and less as the charge travels along, so that one may look upon the wave travelling down the cable as being of continually decreasing amplitude. As the wave travels down the cable with a certain velocity the alternator continues to revolve, that is to say the phase of the current wave applied to the end of the cable is continually changing, so that the phase difference between the alternator wave and the current wave travelling down the cable increases progressively. The net result is that in a very long cable the wave travelling along the cable continually diminishes in amplitude and lags behind the generator in phase.

If the cable is electrically very short there will be practically no diminution in amplitude or change of phase while the wave progresses along it. This is in general the case for the underground cables and power lines in this country at ordinary frequencies, and under these conditions the cable may be considered to be replaceable by an equivalent arrangement of self-inductions and condensers, as shown in Fig. 21, in which the capacity of each of the two condensers is equal to one-half of the capacity of the cable, and the self-induction and resistance of the coil between them are equal to the self-induction and resistance of the whole cable. The pressure rises that may occur in this cable are approximately those already referred to when dealing above with localized self-inductions and capacities.

Very long lines, such as those in use abroad, cannot be considered quite so simply. Suppose a long line is on open circuit at the far end, and, as before, it is suddenly connected to the generator at the zero point of the potential curve. Then the wave of current flows down the line, and when it gets to the open far end it is reflected or turned back on itself and flows back towards the generator; now at this reflection at the far end, the potential difference of the wave is doubled. The wave now travels back towards the generator, where if the generator is assumed to be very large the wave will go to earth quite freely and the reflection will take place with a reversal of phase and no increase in amplitude. The current wave will again travel back towards the far end of the cable where it will again be reflected, and it will travel successively backwards and forwards and so build up to the steady state. Consequently in the steady state of such a cable the voltage of the far end may be looked upon as being built up on a number of components of different phases. The magnitude of the voltage will naturally depend upon the phases and magnitudes of these components. First as regards their magnitude; as the charge travels along the cable the voltage decreases according to an exponential law—

$$V = V_o \epsilon^{-\alpha L}$$

in which α is the attenuation constant. For instance, in a certain cable the quantity $\epsilon^{-\alpha L}$ might at a given frequency be 0·7. This would mean that the voltage at the far end was only 70 per cent of that suddenly applied by the generator, so that in transmission along the cable the first time there is a loss of 30 per cent. This wave is reflected as already mentioned and travels back towards the generator, where it arrives again reduced by 30 per cent, that is to say to 49 per cent of its initial value; the reflection then takes place at the generator and the wave travels back, arriving at the far end with about 35 per cent of its initial amplitude. This adds on vectorially to the initial wave so that the waves at the far end of the cable are a summation of a rapidly diminishing series of waves.

The phases and amplitudes of the components of the voltage at the end depend upon the frequency, the length of the line, and its constants. In order that the components may add up to a considerable total it is necessary that they should all arrive at the far end in the same phase, or more accurately that the phases should differ by a multiple of 2π. As the reflection at the generator end is accompanied by a reversal of phase the travel of the wave along to the end and back must be accompanied by a change of phase of π, *i.e.* the alternator must have changed its phase by $\pi/2$ during the time the wave takes to travel along the line, which means that the length of the line is a quarter of the wave-length at this frequency. This condition leads to a building up of the potential at the end of the line.

Another way of looking at the effect is to consider that the wave which is started flows along the line and after reflection at the open end returns to the generator, where it should arrive at the moment that the alternator has reversed the direction of its E.M.F., so that the returning wave and the E.M.F. of the alternator act in the same direc-

tion and assist one another. This effect, namely the building up of the potential at the far end of the line on open circuit, is generally known as the Ferranti effect, owing to its having first been observed by Dr. Ferranti on the Deptford mains.

In general the velocity of propagation of the wave along the line is less than the velocity of light, say from one-quarter this velocity upwards for ordinary cables and lines, though nearly equal to it for straight wires in space away from other bodies.

At 50 frequency with a cable having a self-induction of 0·5 millihenry per mile and a capacity of 0·25 microfarad per mile the velocity of propagation is about 86,000 miles per second in round figures.

Hence the distance travelled in one-quarter period, or one two-hundredth of a second, is 430, so that the quarter of a wave-length will correspond approximately to 430 miles.

With higher frequencies the length to produce the effect is considerably shorter, so that the effect can become quite marked with the upper harmonics and moderate lengths of circuit, and considerable rises of pressure due to this cause have been observed in the United States.

It is well to point out that a load on the end of the line reduces the effect, so that on loaded lines it soon becomes inappreciable.

With the higher frequencies employed in wireless telegraphy the Ferranti effect is very marked. Aerials are always adjusted with their added self-induction to the quarter wave-length, so that the potential at the free or open end may amount to some hundred times the pressure employed at their base.

With the short cables in use in this country the effect is rarely observed, but it is of considerable importance from the point of view of the sparking and arcing that may take place in switching operations and during faults, which may generate oscillations of a suitable frequency to produce the effect to a very marked degree with comparatively short leads. The magnitude of the effect depends on the resistance being small, which is generally the case in practice.

In making calculations of the frequency which will produce the Ferranti effect on very short lines, the line may be considered to be replaced by the circuit shown in Fig. 21, as pointed out by Dr. Kennelly, and the frequency of resonance of the part B C and D may be calculated by the simple Kelvin formula. A more accurate result can be obtained for short lines of small resistance by taking $2/\pi$ of the capacity and $2/\pi$ of the self-induction of the whole line, and calculating the free period of a circuit composed of a capacity and self-induction having these values.

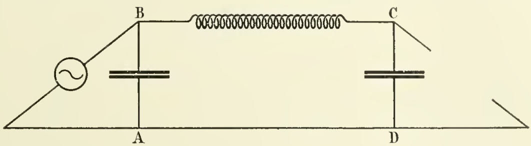

FIG. 21.

Some very interesting cases occur when inductive windings are suddenly switched into circuit; for instance, the high-tension coils of transformers, induction motors, or any alternating-current apparatus. In this case there may be no observable pressure rise between the terminals of the coil, but yet during the initial stages the full pressure which is applied between the terminals of the coil may be so unequally divided between the windings as to produce locally differences of potential far above the normal.

Let us consider the coil shown in Fig. 22, and let us assume that a high voltage V is suddenly applied to it by means of the switch *s*. Now in the steady state the voltage V will be assumed to be uniformly divided among the turns of the coil, so that between the ends of the first turn there will be V/n volts, if n is the number of turns. Now consider what happens at the first moment of closing the switch *s*. The current will not instantly attain its steady value; there will be a preliminary stage, and during this preliminary stage one may imagine that a quantity of electricity is travelling forward along the coil from its end. In other words, that there is a sort of wave front starting from the switch to travel along the coil similar to the charge of a long cable. If the coil possessed no electrostatic capacity, *i.e.* no condenser action, either from turn to turn or from turn to earth, the current would be propagated instantaneously round the coil, and would start to grow from zero in all parts of the coil equally at the same time; but in practice this is never the case, for every coil, however made, possesses some finite though very small condenser action. The wave front therefore takes some appreciable time to travel round the coil, although this time may be exceedingly small. During this progress the potential difference is by no means uniformly distributed along the coil; in fact, the coil may be looked upon as similar to a long submarine cable if one remembers that the electrical constants are very different, and consequently the times of propagation of the disturbance.

In the case of a submarine cable, say an Atlantic cable, if the voltage is suddenly applied at this end, the wave starts off and travels towards the States, and the first trace of its arrival occurs rather less than 0·1 sec. later. In the case of the windings of an ordinary transformer the length of time required for the wave front to travel along the coil is probably less than $\frac{1}{10000}$th of a second. In both cases during the initial stages practically the whole of the potential difference is localized.

The localization of the voltage on the turns of a transformer at the moment of switching it into circuit is of great practical importance and is the cause of many failures. The effect is further aggravated by any sparking which may take place at the switch contacts, which

sets up high-frequency oscillations in the leads connected to the transformer. As the high voltage between turns due to switching in only lasts a very short time, too short to be recorded by an ordinary oscillograph, the failure of the insulation between turns may only take place after a number of switchings, when the insulation between turns having been locally weakened, heating sets in at the normal working voltage and a breakdown of the coil to earth soon follows. For this reason extra insulation is often placed on the end turns of transformers, or choke coils are used in series with them as a protection.

High-voltage motor windings are subject to a similar effect, and with asynchronous motors there is a further possible cause of localization of the pressure on a limited number of turns of the windings, not necessarily the end turns. This depends on the fact that the self-induction and mutual-induction of the different sections of the windings are not necessarily equal, owing to the mechanical difficulties in making the short air-gap perfectly equal all round the machine.

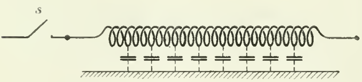

FIG. 22.

The localization effect on the end turns of the apparatus is especially noticeable in connection with the high-frequency oscillations or with the steep wave front currents which may travel along overhead lines after lightning discharges. These are very similar in their properties, but, owing to the much higher voltages which may be induced, much more destructive and difficult to guard against than the steep wave fronts and oscillations that can be set up by switching on apparatus. This effect has been investigated by Jackson.

Switching off ordinary loads is generally safe, for even should the switch try and open the circuit when the current has its maximum value it is improbable that the rate of decrease of the current will be sufficient to produce dangerous pressure rises. On the other hand, abnormal currents and short-circuits may give rise to excessive pressure, as the energy liberated at the break is so large that it may form an arc and blow the switch to pieces. If the rate of break is sufficiently rapid to avoid this, the rate of change of the current may be so great that a dangerous pressure rise is produced. A number of valuable records showing the switching off of large powers amounting to tens of thousands of kilowatts are given in a paper by Marguerre in which practically no rises of pressure are observable, but I think it is unwise to assume that this is always the case. The best means to employ to limit the short-circuit current of generators is one of the problems which faces designers at the moment, both to protect the machines themselves from damage and to reduce the risk of pressure rises on opening the circuit.

The whole question of the rate of change of current that may take place at the moment of switching off is really a question of the suddenness with which the arc or spark between the switch contacts can be extinguished, for except under very exceptional cases it is impossible to break any considerable current without some arc or spark forming at the contacts. The rise due to these causes will, however, be considered in the next sections.

3. Arcs and Sparks.

Pressure rises may in many cases be traced to the properties which arcs and sparks have of facilitating or causing rapid rates of change of current. The properties of an electric arc are somewhat peculiar in that it is one of the few electric conductors which is in general essentially unstable. By this I mean that if the current be increased through an ordinary arc the potential difference between its terminals decreases, producing a further tendency for the current to increase, which if it is not limited by some other resistance in the circuit would tend to increase to an unlimited extent. On the contrary, if the current be decreased the potential difference between the terminals of the arc rapidly rises, tending to suppress the current altogether. In fact, it is quite well known that it is necessary to have a steadying resistance or its equivalent in series with any arc in order to reduce the tendency of the current to go off suddenly to infinity, or to become zero.

This instability of the arc favours the sudden suppression of the current should an arc be formed, and tends to produce pressure rises if there is any self-induction in the circuit, which in practice is always the case. The instability of the arc may be greatly increased if the electrodes are kept cool; for instance, if they consist of large masses of good heat-conducting material. Further, this effect is increased if the electrodes are close together so that they tend to cool the vapour column of the arc. A transverse magnetic field also makes the arc unstable. Shunting the arc with a condenser greatly increases this instability, because should the current through the arc decrease due to any accidental cause the potential difference between the terminals of the arc will increase. This will tend to cause the current to flow into the condenser shunting the arc, which current will be diverted from the arc. It should therefore tend to reduce still further the current through it, rendering the conditions more unstable than without the condenser as a shunt.

A great deal has been written about the difference between arcs and sparks. In my mind the fundamental difference between an arc and a spark is that in the arc the electrodes are being continuously volatilized, and the vapour of the electrodes takes part in the passage of the electric current. The spark, however, is generally of an intermittent or a transitory nature, the electrodes are not appreciably volatilized, and the current is largely transferred through the air. It is pretty obvious that there cannot exist any clear line of demarcation between the two phenomena, and that the one merges into the other under the above definition, depending on the mass of volatilized electrode present in the vapour column. The properties of the spark are more difficult to investigate than those of the arc owing to its transitory nature, but there seems little doubt that they are essentially similar with regard to instability. In fact there are reasons to suppose that the electric spark possesses the same instability as the arc but in an enhanced degree.

Any arcing or sparking taking place in a circuit is liable to set up oscillations which may give rise to dangerous

pressure rises. It is therefore necessary to consider the types of oscillations which may be produced by arcs or sparks. The best-known case is the oscillatory discharge or charge of a condenser such as is used in wireless telegraphy. Fig. 23 shows the usual connections.

If the source of supply is high-tension alternating, each time the condenser charges up to a sufficient voltage the gap *s* will break down and an oscillatory discharge will take place. This discharge repeats itself each half-wave, or several times per half-wave if the conditions are suitable. The activity of the oscillations depends very much on the condition of the spark at the gap *s*. If a lot of conducting vapour is formed, or if the electrodes remain very heated so that the gap does not recover its insulating properties very quickly, then after the first discharge the condenser cannot be charged to so high a voltage, and the activity of the oscillations falls off.

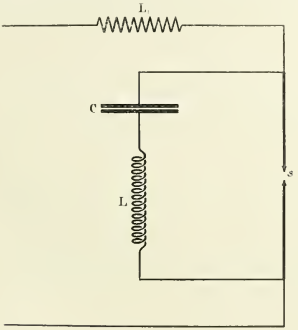

FIG. 23.

For this reason sparks taking place between large masses of metal which are good conductors of heat or in a magnetic field are more likely to be active than those that take place between carbon electrodes. If after the spark takes place the generator current follows, forming an arc and a quantity of vapour, the oscillations are generally reduced in activity.

If the supply is continuous current, oscillations can still be produced provided that the arc is such that $\delta V/\delta I$ is a negative quantity, where δV is the change in voltage produced by a small change δI in the current through the arc, and that the resistance of the oscillatory circuit composed of L and C is low enough. The quantity $\delta V/\delta I$ is not in general negative for large-current arcs in air, so oscillations due to this cause do not seem probable at first sight. Large-current arcs in gas and in magnetic fields can, however, produce powerful oscillations. Further investigation is required as to whether under the initial conditions of the formation of large-current arcs the instability may not be such that oscillations can be produced.

A water model can be made which will to some extent indicate the instability of the arc and will give a good representation of how the oscillations are produced. In the actual model the arc is represented by a mushroom valve. The pressure of the valve on its seat is so arranged that the pressure tending to re-seat the valve diminishes very rapidly as the valve lifts. Water is admitted beneath the valve, flows through the valve into the vessel which contains it, and overflows. In order to indicate the difference of pressure on the two sides of the valve which represents the arc a glass pressure-column is introduced into the pipe leading to the valve and quite close to it. As the water overflows freely from the tank in which the valve is immersed, the pressure on the side of the valve may be taken as our zero of reference, and consequently the height of the water column in the pressure tube above or below the level of the overflow gives the pressure underneath the valve.

If water be admitted from the tank below the valve the pressure in the pressure tube rises to a high value; finally the valve lifts, *i.e.* the arc is struck, but the pressure still remains high. If, however, the flow of water is increased, the valve will open considerably and the pressure below it will decrease. If nicely adjusted this effect can be made to take place over a considerable range.

If instead of connecting a pressure tube of small bore indicating the pressure on the underneath side of the valve

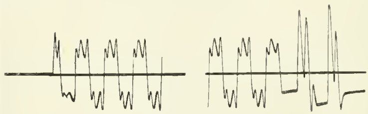

FIG. 24.

a large diameter tube be introduced so that the water column in it has a periodic time of its own and is able to oscillate similarly to the condenser circuit shunting the arc, oscillations will be set up in this column, and if the periodic time of the liquid in this column be altered, the period of the oscillations will be altered; this can easily be done by connecting air vessels of different capacity to the open end of the tube, so altering the controlling force acting on the water, in other words altering the capacity of the circuit shunting the arc.

With this water model a great many of the properties of arcs both intermittent and oscillating can easily be shown. The one point of difficulty in constructing the model is to obtain a force acting on the valve which decreases rapidly when the valve lifts and which occasions no friction. So far the only successful method I have found is to hang from the underneath side of the valve a piece of soft iron which nearly touches the pole of a small electromagnet. This gives a force which without any friction rapidly decreases as the valve lifts and works very well.

Intermittent discharges may take place either with alternating or continuous current, and give rise to oscillations as follows:—If the generator has a very drooping characteristic, or if L_1 (Fig. 23) is a very high resistance or inductance, then the condenser will take an appreciable time to charge up to the discharge voltage. After the discharge, which may be oscillatory, has taken place a

certain time must elapse before the condenser is again charged to a sufficient voltage, so that a regular succession of charges and discharges will take place even with a continuous-current supply. The time to charge the condenser depends for a fixed generator voltage and length of gap on the capacity of the condenser and on the impedance of L_1, including that of the generator. If the impedance is not too large the successive discharges may follow one another very rapidly. It is possible with a continuous-current supply at very high voltages, and spark-gaps that are well cooled, to make the sparks follow one another tens of thousands of times per second. Probably these intermittent discharges play a considerable part in the production of pressure rises.

The practical applications of the above short résumé of the production of oscillations by arcs and sparks must now be considered. The only capacities available are the capacities of the connections, the network, the feeders, and the windings of the machines to frame. The self-inductions available are those of the windings of the transformers and machines and of the connections, network, and feeders.

Sparks and arcs may in practice be formed at switch contacts or when faults take place. Under normal working conditions sparks mainly take place at the switch contacts, but when large currents are being broken regular arcing is observed at the contacts. In the case of a fault, except a sparking fault to earth with both poles insulated, the discharge at once takes the form of an arc. I have already mentioned that in switching on and off cables on open circuit, pressure rises may be produced should the switch contacts chatter in going in or out. A similar effect can easily be produced by sparks between switch contacts if they are held stationary and almost touching on sufficiently high-voltage alternating circuits. For in this case at the peak of each half-wave a spark will take place tending to charge the cable first in one direction and then in the opposite. These reversals are naturally attended with the pressure rise already referred to under "vibrating contacts." Fig. 24 is a good example of the rises that may be produced when a feeder on open circuit is disconnected, intentionally allowing the switch to spark in air between its brass contacts. The voltage has risen from the R.M.S. value of 2,000 to 5,100 at the last spark before the final break.

When switching off an inductive circuit a high pressure may occur should the current be interrupted suddenly. This well-known effect in the case of continuous-current circuits can also take place on alternating-current circuits when using oil-break switches, though it is usually supposed not to be the case. It is true that the oil-break switch in general does tend to open the circuit when the current is in the neighbourhood of the zero value, but this is not always the case. Fig. 25 shows the switching on and off from a 2,500-volt sine-wave machine of a large transformer on open circuit. The oscillograph in this case was connected between the terminals of the switch so as to show the pressure rise at the switch, which amounted at the moment of switching off to 11,000 volts. The rise in pressure lasted about $\frac{1}{20}$th of a period, that is to say about $\frac{1}{500}$th of a second. It is to be noted that the switch only opened the magnetizing current of the transformer. When making this experiment there was a small piece of cable between the switch and the transformer, and there is no doubt in my mind that the capacity of this cable materially assisted the suppression of the current at the spark, and consequently increased the pressure rise.

FIG. 25.

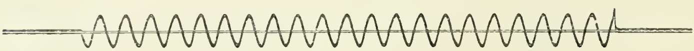

FIG. 26.

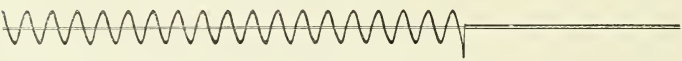

FIG. 27.

I have already mentioned that if an inductive circuit carrying a continuous current be interrupted by a switch, a condenser shunting the terminals of the switch will stop the arcing at the switch contacts and produce a serious pressure rise. The following tests show that a similar effect occurs with alternating currents. A transformer of about 150-kw. capacity was switched on and off by means of an oil switch from the 2,500-volt mains. The measurements were made between the terminals of the transformer. The connections between the switch and the transformer were very short. In this case after switching off a number of times very few pressure rises were observed. The worst is shown in Fig. 26, where there is a peak of 5,500 volts.

On introducing a length of about 60 yards of cable between the switch and the transformer nearly 60 per cent of the breaks produced pressure rises, the worst of which is shown in Fig. 27, the maximum value being 7,500 volts. These two tests illustrate very well the effect of capacity

shunting the switch contacts in increasing the tendency to pressure rises when switching off inductive circuits. It may be said that introducing a cable between the switch and the primary of the transformer does not constitute a condenser shunting the switch contacts, but a little consideration will show that the capacity of this cable to earth is in series with the capacity to earth of the supply main, and that these two condensers in series do shunt the switch contact; this is the usual arrangement whenever the switch has connected to both terminals a length of cable which has any appreciable capacity to earth.

The arcs which take place when fuses blow have similar properties, and as in this case they are nearly always shunted by the capacity of the cables connected to them, similar rises take place. Fig. 28 shows a short-circuit on the end of a feeder connected to a 2,000-volt 400-kw. generator which was allowed to remove itself by means of a fuse.

The big initial rush of current and the pressure rise attendant on the blowing of the fuse are clearly shown, the maximum value being 4,200 volts. Another example is shown in Fig. 29, in which a light fuse was suddenly connected as a short-circuit to the secondary of a 10,000-volt transformer; the fuse blew instantly. During the short-circuit the potential difference between the terminals of the secondary of the transformer was of course reduced to zero. This lasted for about half a period, when the fuse melted and a rise in pressure of 27,000 volts was recorded. In this case the great suddenness of the interruption of the current was in part due to the fineness of the fuse used, leaving very little volatilized metal to form an arc, and partly to the capacity of the leads connecting it to the transformer. A fine series of records of switching at high pressures, and the attendant rises are given by Faccioli which confirm the above remarks.

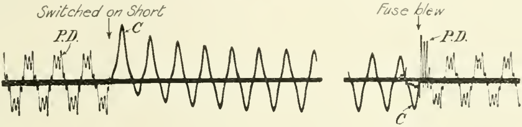

FIG. 28.

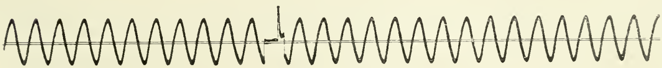

FIG. 29.

Sparking at switch contacts may also set up oscillations along the leads in much the same way as the oscillations are set up in wireless aerials by sparking into them at their bases. The mere sparking into the lead will not in general set up very violent oscillations because these oscillations will have to pass round the generator, but should there be considerable capacity between the generator and the switch contact oscillations may be set up which will pass through the condenser to earth. In this case the apparatus situated at the end of the lead might be subjected to considerable strain, and might run the risk of having its end turns damaged owing to the high-frequency oscillations set up along the lead.

At high voltages any sparking taking place between one point of an insulated circuit and earth will set up oscillations in the leads, connections, and apparatus. The whole circuit may be considered as equivalent to a complicated aerial system of a wireless transmitter which is excited in the manner generally spoken of as plain aerial, that is, with a spark between it and earth. The effect of this is to set up a number of high-frequency oscillations in the system, producing high potentials at all points where reflections of the oscillations may take place, such as open ends and the connections to apparatus having appreciable self-induction. Berg has investigated a number of cases and has shown how a spark fault to earth may produce very high voltages localized on the end coils of transformers, etc.

Turning next to arcs, I have not yet come across a well-authenticated case in practice of an arc acting as a musical arc and producing dangerous pressure rises. It is easy enough to produce them in the laboratory, but the conditions in practice do not seem suitable for maintaining continuous oscillations. I am of the opinion that there is a great deal more risk in intermittent arcs maintaining oscillations than from the arc producing continuous oscillations.

The opening of large currents, whether it be by switches or fuses or by faults which burn out, is always attended by the risk that the current may be suppressed too suddenly and that the energy stored in the self-induction of the circuit may not be dissipated. In this connection I am inclined to think that sufficient attention has not been paid to the self-induction of the leads and cables. Although the self-induction per mile of the cables is comparatively small—it may apparently range from a fraction of a millihenry for cables very close together to some 5 millihenries for conductors like track rails on continuous-current railways—yet the amount of energy that may be stored is considerable owing to the large currents that may flow at the moment of short-circuits or faults. It is to be noted that as the great part of the magnetic field is situated in air, should the current be suddenly suppressed the whole

of the energy is liberated at once, giving rise to very high voltages. This is not necessarily the case in machines and apparatus, as with these quite a considerable part of the self-induction may be due to the lines of force threading the iron, and it is impossible for these to collapse so suddenly on to the conductors owing to the eddy currents they would produce in the mass of material; therefore when they do collapse some of the energy is wasted by this means and the pressure rise is reduced.

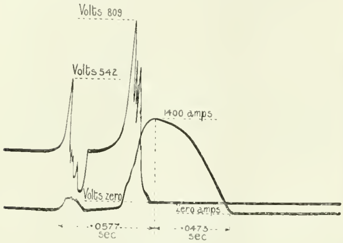

FIG. 30.

The exact values of the self-induction and capacity of the cables used for carrying continuous currents do not seem to have received much attention. Approximate calculations can, however, be made. As an example, the self-induction of one mile of two 0·5 sq. in. cables laid in non-metallic ducts at 4-in. centres is about 1·6 millihenries, the capacity about 0·1 microfarad, and the resistance 0·176 ohm. Taking these figures the maximum possible voltage rise neglecting the self-induction of the machine is 252 times the current suppressed, if the cable is considered to be equivalent to localized condensers and a self-induction arranged as in Fig. 21. For 500 amperes interrupted, the limit of the pressure rise might thus be 126,000 volts.

to be more stable and a large amount of vapour is produced from the electrodes, yet the appearances seem to be that in the case of still larger currents the arc goes out with great suddenness. In ordinary cases of supply mains there may be two causes which tend to this quenching of large-current arcs. First and foremost, the considerable magnetic field produced by the current itself. Second, and this applies to insulated mains in enclosed spaces, the production of a gas surrounding the arc due to volatilization, and the splitting up of the insulating material. Third, the cooling effect of the large masses of the metal which are usually present in circuits intended to carry large currents. Whatever the true explanation may be, it seems to me that the properties of large current arcs, both continuous and alternating, require further investigation, especially as regards quenching. Some tests made by Collis show very well the pressure rises that may occur on breaking continuous-current circuits. Fig. 30, taken from his paper, relates to a magnetic-field blow-out circuit-breaker operating on a dead short-circuit. The voltage rose to 809, and the steady value after the circuit-breaker had operated was 226. The arc in this case appears to have been suddenly extinguished, producing the high-pressure rise, and then to have re-started, causing a second but smaller rise.

In order to illustrate the pressure rises that may occur in cables due to short-circuits, I have prepared a model line, somewhat similar to that used by Wagner and consisting of a number of sections, which has a total self-induction of 0·24 henry and a total capacity of 6 mfd. to earth distributed along it. The resistance is 27 ohms. This line may be looked upon as representing 10 or 15 miles of cable, in which the self-induction, capacity, and resistance per mile are, roughly, increased tenfold. Consequently the frequency of the line is reduced tenfold. With this line connected to the ordinary continuous-current mains it is possible to make short-circuits anywhere along it and to observe on the oscillograph the attendant pressure rises. These can be quite easily made to repeat themselves, and the wave forms can be projected on the screen. The tests made with this line indicate how easy it is to obtain very

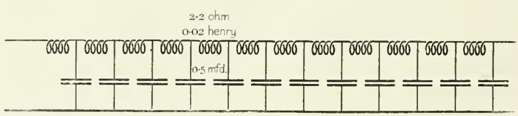

FIG. 31.

If a short-circuit is suddenly interrupted somewhere in a long cable a high-voltage wave front starts from it and travels in each direction towards the ends of the cable, where it may be reflected if the end is open or connected to a high self-induction, its amplitude being then doubled.

There is no doubt that in many cases of short-circuit—whether of a continuous current or of an alternating current—the current is very suddenly suppressed. The arc is quenched somehow, to use a wireless term. It is easy enough to quench arcs with small current, but with medium currents, say a few 100 amperes, the arc appears

considerable pressure rises by means of short-circuits which are suddenly opened, and they also indicate the strain at the end of the line due to the reflection at that point of the wave that travels along it each time a short-circuit is removed somewhere along the line.

I have attempted to summarize as briefly as possible the causes of pressure rises. They are numerous. Very small changes in the conditions will sometimes make all the difference between considerable pressure rises and none of importance. Pressure rises are illusive to investigate; time after time one will repeat the test without

hitting the exact condition, and then perhaps at last, after a number of trials without having made any apparent change, a considerable rise will be observed. No faith can be put in observations of pressure rises unless they are repeated many times. Tests repeated once or twice are not conclusive evidence if a rise is not observed. The importance of these rises to electrical engineers is well recognized. The means to prevent them occurring, and the precautions to be taken to try and relieve the insulation from the strain when they do occur, are matters which would take me too far for this address to-night.

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NEWCASTLE LOCAL SECTION: CHAIRMAN'S ADDRESS.

By C. VERNIER, Member.

(*Address delivered 20th October*, 1913.)

ABSTRACT.

Previous to the year 1900, public electricity supplies in this country were, generally speaking, chiefly utilized for lighting. As the result of an investigation in 1898 a Joint Committee of the House of Lords and the House of Commons made certain recommendations, which resulted two years later in the granting of statutory powers to several undertakings formed for the purpose of supplying electrical energy over very large districts, covering in many cases some hundreds of square miles.

The advantages which have been claimed for these undertakings, and which are no longer open to question, may be briefly summarized as follows :—

(1) The low capital cost per kilowatt of generating stations and the increased economy in running charges obtained by the use of very large generating units.

(2) The development of high load and diversity factors, resulting from the varied uses which are made of the electrical energy supplied.

(3) Low fuel costs obtained by the favourable location of generating stations and the opportunities afforded for the utilization of waste heat and other forms of waste fuel.

The important influence of low capital cost upon the cost of producing electrical energy was clearly brought out in a paper contributed to this Institution by Messrs. Merz and McLellan in 1904.* Since that time much closer attention has been given generally to the reduction of the capital cost per kilowatt of power stations, and in view of the steadily increasing price of coal it is a matter which must continue to receive great attention. Of even greater importance is the development of a high load factor and high diversity factor, both of which effect a reduction of the capital charges per unit by enabling the same plant capacity to deal with a greater annual output. The maximum economy in coal consumption can only be attained by the use of large generating sets, which further lend themselves to the lowest capital cost of installation, while on the other hand where fuel is cheaply obtained, as for instance in the case of waste heat or gas, the installation of smaller units at a higher capital cost per kilowatt may be quite justified. In general, the higher the price of fuel, or the poorer the load factor, the less can a high capital cost be defended on economical grounds. It may also be stated that in a large scheme the cheaper the fuel the more desirable it is to run the plant at a high load factor ; therefore, any stations operating with cheap fuel, such as cheap coal, waste heat, or water power, must be run as nearly as possible continuously at 100 per cent load factor, the ordinary coal-fired stations dealing only with the fluctuations of load. This is where the producer of waste heat finds it to his advantage to co-operate with a power company. Without this co-operation it is scarcely possible for a power station installed by such a producer to utilize the whole of the waste heat available at all times of the day and night, or in other words, to run the station as far as fuel permits on a 100 per cent load factor, and thus to obtain, as the power company can do, the best possible results.

If we now examine the conditions under which electrical energy is produced in this country, it is clear that with a few exceptions we are very far from according with the conditions that I have described as essential to a low cost of production. The multiplicity of small generating stations, some 40 per cent of which are of a capacity under 1,000 kw., supplying small districts, inevitably results in high capital charges, poor load factors, and high fuel and running costs. We, who are familiar with the extraordinary developments that have taken place in the production and utilization of electricity on the North-East Coast during the past 10 or 12 years, will be under no misapprehension as to the disadvantage under which the greater part of the country continues to be placed by this subdivision of the means of production and distribution.

When we note that the use of electricity from public-supply sources in that portion of the North-East Coast served by the power companies has increased by over 3,200 per cent within the past 10 years,* and that as the result of a cheap and abundant supply of electrical energy new industries are springing up in our midst, it is surely a matter for regret that similar rapid progress has not taken place to the same extent elsewhere.

Dr. Ferranti, in his inspiring address to this Institution three years ago,† set before us an ideal of what electricity supply should be, and it is perhaps pertinent to ask ourselves what we in this country are doing towards the realization of that ideal. Do we not see each year existing generating stations of small and moderate size being extended ? Generating stations which in many cases are quite unfitted by their unfavourable situation to achieve the economical production of electrical energy. Then what of our load factors ? How very few (less than 3 per cent) of our electrical undertakings of to-day can exceed even a 25 per cent load factor. Again, how many of our undertakings can profitably avail themselves of the utilization of such waste heat as may exist in their neighbourhood ? Although in this district we certainly have a large share, yet we have no monopoly of waste heat and waste gases from coke ovens and blast

* *Journal I.E.E.*, vol. 33 p. 636, 1904.

* In that portion of the North-East Coast not served by the power companies, which includes many of the large towns, the corresponding increase is under 450 per cent, which is also about the average for the whole country for the same period.

† *Journal I.E.E.*, vol. 46, p. 6, 1911.

furnaces; in fact, the waste heat from these sources in existence in this country would if fully utilized be more than sufficient to operate the whole of our existing public electric supply stations, with a combined maximum load last year of between 700,000 kw. and 800,000 kw.

The first step towards the realization of Dr. Ferranti's ideal must inevitably be in the direction of the centralization of all coal-fired generating plants into large power stations supplying in bulk over very large districts, so as to obtain the benefit of large outputs and increased load and diversity factors. These stations will have as far as possible to be interconnected together, while all available sources of waste fuel must be fully utilized. What, then, is the chief obstacle to the centralization of our electric power supply? Is it not largely the opposition which is almost invariably offered by municipal authorities, and particularly by the more important of them, to the exercise of private enterprise within their borders? It will not be easily forgotten how strenuously the Power Bills were opposed by the municipal authorities, with the result that in most cases the larger towns and industrial centres were entirely excluded from the area of supply, while the supply in bulk within the area of any existing undertakings is usually made subject to their consent. To this fact, coupled to the aversion of many of our local authorities to enter into contractual relations with public companies for bulk supplies, must be attributed the slow progress which many of the power schemes have achieved.

Of course it may be argued that the centralization of power supply is not of necessity a matter to be undertaken by private enterprise, in fact the Electric Lighting Act of 1909 affords facilities for the combination of a number of local authorities, but the jealousy of control between neighbouring authorities appears to be an even greater obstacle than those previously mentioned, and, so far as I am aware, there is but one solitary instance of such a joint scheme between municipal undertakings in the history of electricity supply in this country, viz. that of the Stalybridge, Hyde, Mossley and Dukinfield Joint Board, which was formed as long ago as 1901. Be it further noted that while the Electric Lighting Acts afford to local authorities the right of combination or to promote joint schemes, similar schemes between a number of companies or between local authorities and companies are denied, and even the supply from a single generating station of two or more districts scheduled under separate provisional orders but operated by a single company cannot be carried out without special Parliamentary authority; all powers granted to companies, if we except power companies, being subservient to the right of purchase of company undertakings by the local authority for the district.

Although from time to time we have been assured that the position of our electric supply industry was in no way behind that of other parts of the world, I question very much whether we can make the same statement to-day, in view of the rapid progress which is taking place in other countries at the present time. For our part, and I speak in a general sense of the whole electrical supply industry of this country, the progress of the past 10 years is surely nothing to boast of, in view of what might under more favourable conditions have been achieved. If we assume that our electric supply industry commenced in 1890—although a few undertakings were started earlier than this—at the end of the first 13 years the annual consumption had risen to 247 million units in round figures, while in the next 10 years (1903–13) this consumption amounted to 1,318 million units, or an increase of 433 per cent. If the pioneering work of the first-named period is considered, few, I think, and least of all in this district, will be prepared to agree that the increase within the last 10 years represents the rate of progress which we ought to expect. The reason for this is clearly that the great majority of our undertakings by their operations on the restricted scale created by their condition of municipal isolation are not in a position to supply the larger users such as railways and industrial power consumers of all kinds. Nor is it possible that we shall ever be in such a position, so long as for sentimental or other reasons it is considered essential to retain a power station for each town or district, irrespective of its size or facilities for economical production. It is not surprising that under these circumstances an examination of the tables published by the *Electrical Times* shows that out of 287 undertakings whose generating costs are analysed (July, 1913) only five, or less than 2 per cent, have a works cost of 0·5d. per unit or under. Therefore, although it may sound like reiteration, we must first divest ourselves of this "one town one or more power stations" idea before we can hope to make any rapid progress.

That many of our undertakings are experiencing the pressing necessity for larger outputs and higher load and diversity factors is evidenced by the special efforts which are being made to develop electric cooking. To those of our undertakings especially whose operations are circumscribed by limitations of the area of supply, this development must be of a particular importance, and it is so far fortunate that their inability or unwillingness to improve their position by other possible means has compelled them to break new ground and direct their attention to the energetic development of this business. Meanwhile, unlike the small power business, which in many places has reached no unsatisfactory proportions, the development of the heavy industrial power supply over a large part of the country appears to be languishing, and yet how much remains to be done may be seen from the last Census of Production, which gives the total horse-power of engines in use at that date (1907) in the factories and mines of this country as $10\frac{1}{2}$ million, of which $1\frac{1}{2}$ million horse-power, or only some 14·3 per cent, represented the total plant capacity of public electric supply undertakings. More recent complete figures are not available, but some measure of the increase of horse-power available in our generating stations can be obtained from Garcke's "Manual of Electrical Undertakings," which shows an increase of plant capacity between 1907 and 1913 of just over one-half million horse-power for those public supply undertakings which furnished returns, or rather less than the average rate of increase since 1890. I have been unable to obtain any figures bearing upon the total horse-power of engines in use in the country at the present time, but assuming for the purpose of comparison that no alteration in the figures has taken place elsewhere than in our public electric supply stations, our progress would be represented by an increase during the past five years of 4 per cent of the total. A further surprising fact shown by the last Census of Production is that there was approximately 1,000,000 h.p.

in private hands utilized for generating electrical energy, which produced an output equal to fully 62 per cent of the entire output of our public electric supply undertakings. Comment would be superfluous.

The most important development of the not very distant future will undoubtedly be the electrification of our railways. This branch of work, if we except the London tube railways, has not progressed as rapidly as we should wish, and many reasons have been advanced in explanation of this, of which perhaps the most important is the heavy capital cost of carrying out the conversion. This will, however, become of less importance as traffic further increases and as the alternative of carrying out heavy construction works becomes more and more pressing in the future. Steam locomotives have about reached the maximum dimensions allowed by the present load gauge, and the demand is still for heavier loads and more frequent traffic—two problems which electric traction is eminently fitted to solve.

Now as to the supply of electrical energy to work our railways. Are we going to repeat the mistakes of the past, and add to our already too numerous generating stations by compelling our railway companies to put down their own generating stations, as several have done already? This load, at any rate, is not one which for various reasons our municipalities can ever hope to touch, and there is, I think, no better illustration of the shortcomings of the present state of our electric supply industry having regard to its ability to meet all demands. It is certain that the ability to supply a likely demand will largely create such a demand, and if we wish to see a more rapid development of the electrification of our railways, the electric supply industry must place itself in a position to supply all the requirements of our railway companies at a rate which will induce these companies to undertake electrical working. It is not to be supposed that our railway companies would expend the necessary capital for putting down generating stations of their own if a sufficient, cheap, and, above all, a reliable supply were to be obtained from public supply sources, a fact which is already well recognized both in America and on the Continent, not to mention Tyneside.

It appears to me that here lies the key to the future position of our electric supply industry. There would seem to be but two alternatives once the electrification of our railways begins in earnest; either, as I have said, our public supply undertakings must then be in a position to undertake the supply of all the requirements of our railway companies, or our railway companies will themselves put down large generating stations, and, as a certain stage of their electrification developments, will inevitably seek to supply other undertakings in bulk. In either case the compelling agency will be that of larger outputs and the better load and diversity factors to be obtained by co-operation. The balance of advantage should obviously lie with us, who are first in the field, and who ought, but for the reasons which I have endeavoured to set out, to be in a position to supply a railway company's demand better and more cheaply than it could supply itself, having regard to all the economies rendered possible by a joint load. There is, further, a vast and practically virgin field in the supply of electrical energy for electrochemical and electrothermal processes, which, however, will only be secured at rates which are but a small fraction of the present works costs of the large majority of our undertakings. In this field, so far, a few of the power companies stand practically alone, and chiefly those operating in this district, where, as a result of the electrical facilities offered, a number of important new industries have erected works adjacent to the power stations of these companies.

If our position is now relatively unsatisfactory when compared not only with other leading countries, but especially, and I think this is the more correct view to take, with what it should be considering our industrial supremacy and the density of our population,* it is surely a matter of the first importance that the causes which at present hamper the progress of the industry should be inquired into, and that the best means to remove these disabilities should be once more discussed and formulated in the light of present-day experience. This is a question, it seems to me, which the Institution cannot afford to ignore.

It will be of interest to observe that public electricity supply in Germany has developed on very similar lines to that of this country, in so far as many of the local authorities established their own works. Perhaps in one respect their condition was even worse than ours, for in 1909 it was estimated that 80 per cent of these municipal works were of a capacity under 500 kw. Germany is at present wrestling with this problem of the centralization of power generation, which we ourselves must eventually face, and is putting down large stations for a supply in bulk, many of them in connection with iron and coal companies, utilizing waste heat from coke ovens and unsaleable qualities of fuel. The co-operation of municipal authorities is being secured in some cases by buying out municipal undertakings upon terms advantageous to both sides, but more usually by giving these municipalities a financial interest in the power company. As an instance, the municipality of Strasburg takes the whole of its supply from a power company, in which it owns a large number of shares. This company supplies also some 70 communes in Alsace-Lorraine. As the result of the operations in 1909, the municipality received dividends and a share in the profits amounting approximately to £38,000, which, after deducting 4 per cent interest on its invested capital, left a balance of over £21,000 for the relief of local taxation. In other instances, groups of urban and rural authorities co-operating with a power company have the option of subscribing for ordinary shares in the promoting company, usually up to 40 or 50 per cent of the total capital, or in some cases, when wishing to avoid risk, to preferential shares with a fixed dividend and a further share in the profits. In each case the municipalities are directly represented on the board. The mutual advantages are obvious, in that the companies enjoy the benefit of the greater facilities afforded for raising capital, while the community through its directors maintains a live interest and a share in the control of the undertaking. Such schemes of harmonious co-operation it must be admitted cannot fail to hasten the solution of this problem.

* The density of our population in England is twice that of Germany, $3\frac{1}{2}$ times that of France, and $21\frac{1}{2}$ times that of the United States. This has an important bearing on the cost of transmission and distributing electrical energy, and is all in favour of the centralization of supply in the more densely populated countries, yet the more sparsely populated country is that one which has so far gone furthest in this direction, and vice versâ.

It is perhaps in the United States of America, however, that the centralization of electric power production and distribution is making the greatest progress, and it is also remarkable that in that country the supply of electrical energy is chiefly in the hands of private enterprise. We have nothing to compare with the electric service in Chicago, with its maximum load of 230,000 kw. (compared with 20,000 kw. 10 years ago), or with more urban supplies such as the Public Service Corporation of Northern Illinois, which supplies 46,000 consumers in 150 communities, whose combined population is only one-half million, distributed over a tract 150 miles long, and has a load factor approaching 70 per cent. This load factor in itself is a striking example of what can be achieved by supplying various demands over very large areas. Another example, out of many which may be quoted, is the Central Illinois Public Service Company in the same State, which is gathering into one management and system the electrical requirements of a rural district of 350 miles radius (larger than the United Kingdom) with a population of only a quarter of a million, whose present 90 local generating stations will shortly be replaced by a small group of modern central stations.

The principle of State regulation of public utility services, which not only include electricity supply, but also gas, water, telephones, telegraphs, tramways, light railways, and railway services, is that which finds its adoption in the United States under the description of Public Utility Commissions. These Commissions, which are of recent origin and adoptive for each State, are appointed to deal with all questions relating to public services, such as the ratification of franchises, the settlement of disputes between undertakers, the revision of rates, amalgamations into joint schemes, the approval of new issues of share capital, technical regulation, and inspection, and not only to regulate but to press forward the development of such services. What the effect of these Commissions may be upon the ultimate development of the electric supply industry in the States cannot yet be judged, but I have looked in vain for any serious criticism by those most nearly concerned of the principle there adopted, while the remarkable strides which are taking place in the consolidation of central-station interests at the present time tend to show that their effect is on the whole beneficial.* It would seem, however, as if the municipal question obtrudes itself even here, as a few of the acts specially exclude municipally owned public utilities from the regulation of these Commissions, while there is further a "Home Rule" question; large cities, for instance, Chicago, seeking, so far without success, to establish their own Commissions in place of being merged in the more usual State Commissions.

The use of overhead wires in this country has always proved a matter of some difficulty, and some of the complaints which have been made from time to time have been as follows: The objection of the Board of Trade to the use of overhead wires; the difficulty of obtaining wayleaves across country, and the absence of legislative assistance in this matter; and the arbitrary powers granted to local authorities. With reference to the first of these complaints, whatever may have been its attitude at one time, there is no doubt that for a number of years the Board of Trade, thanks largely to their electrical adviser, has facilitated the use of overhead wires in every possible way, with due regard to public safety. This must ever be our first consideration, and I do not think there are many of us who would wish to see erected in this country examples of overhead work, for instance, of the type common in large towns in America. But without going to such extremes in cheapness of overhead construction as is frequently met with there, there is yet a substantial saving in first cost, even with the very best construction, by the use of overhead wires in place of underground cables. The higher the voltage the greater the possible saving becomes; while at pressures exceeding 30,000 to 40,000 volts three-core cables for three-phase transmission can no longer be used, except perhaps in short lengths. It is only necessary to add that the power companies in this district have already 170 miles of overhead transmission lines, mainly operated at 20,000 volts, as evidence of the facilities which have been enjoyed for a number of years.

The difficulty and delays in obtaining wayleaves is a serious obstacle in the development of overhead construction, and our position in this respect compares very unfavourably with that of other countries, notably Italy and Switzerland, which have adopted legislation compelling the grant of wayleaves for overhead lines across private lands. Such works are there viewed as of public utility, and private interests are not allowed, subject to compensation, to take precedence of the general interests of the community. However much we may feel that similar legislation would benefit the electric supply industry, we have but to examine the privileges conferred by Parliament upon our Post Office—a State department with unusually wide powers. These are contained in Section 2 of the Telegraph Act, 1892, and Section 4 of the Telegraph Act, 1908.

While some attempt has been made to recognize the principles of public utility to which I have referred, the powers granted are in such a form as to render them of little or no practical service; in fact I am not aware that they have ever been exercised. We unfortunately cannot hope to obtain greater powers than the Post Office, which has a Cabinet Minister to look after its interests, and, further, such a different view is here taken of the rights appropriate to the ownership of land than is common in more democratic countries, that I am not at all sanguine of our being able to secure greater facilities from Parliament possibly within our generation.

It follows that the use of overhead wires for transmission purposes is at present to a large extent at the mercy of our landowners, but we in the north are fortunate in the fact that the land is largely in the hands of large owners, whose interests are so intimately bound up with the industries whose needs we seek to supply, or, if not, who are already so well accustomed to wayleave matters in connection with the mining industry, that, apart from delays, we do not experience the same difficulties as are perhaps strongly felt in some other parts of the country. The slow progress of negotiations is, however, a serious, but in the circumstances an inevitable, objection, which we must at present accept with the best grace possible.

The Electric Lighting Acts have probably done more to discourage overhead wires than all the rest put together by

* A leading New York banker has recently stated in an address that the electrical industry in the States can profitably employ a capital of £80,000,000 per annum for the next five years.

stipulating that before any overhead wires are erected the consent of the local authority must be obtained. It will probably come as a surprise to some present this evening to learn that this stipulation not only applies to the erection of overhead wires in public streets, but to all overhead wires, even if erected entirely on private land. It is difficult to understand what could have been in the minds of the framers of these measures, when we contrast the position of non-statutory undertakers with statutory companies. The former, of course, are not at all bound by the Electric Lighting Acts, with the exception of one single clause, to which I shall refer shortly. Thus an individual or company which does not work under an Act or Provisional Order can erect overhead wires on private land without the consent of the local authority. Further, such an individual or company, in the absence of special local by-laws, of which very few are in existence, can erect overhead wires across public roads without seeking any consent from the local authority, provided the consent of the owners of the soil on each side of the road is obtained, and also that the wires are erected at such a height above the roadway that no obstruction is caused. Lastly, non-statutory undertakers are not compelled to erect their works in the first instance in compliance with any regulations of the Board of Trade, except that under Section 4 of the Electric Lighting Act, 1888, it is provided that the Board of Trade may, if it thinks fit, serve a notice upon the owners of such overhead lines requiring that they continue to be used only in accordance with such regulations as the Board may prescribe. As the Section of the Act referred to was obviously intended to bring under the control of the Board of Trade all overhead lines erected by non-statutory owners previous to the passing of this Act, it is somewhat extraordinary that the serving of a notice upon the Board of Trade before the erection of further lines was not made compulsory under the Acts. Non-statutory owners, such as iron and steel manufacturers, collieries, and others, have therefore a roving commission to erect overhead wires on private land and, with few exceptions, across public roads without seeking the consent of either the local authority or the Boad of Trade. In my opinion it is essential that an early opportunity should be taken to amend the Electric Lighting Acts in this respect, for if, as all agree, regulations are essential in the case of statutory undertakers, how much more are they necessary in the case of non-statutory bodies, who are usually the least qualified by reason of their not being primarily engaged in electrical work, and whose interest in the matter is frequently limited to considerations of the lowest tender.

Efforts should also be made to secure a curtailment of the absolute veto of the local authorities in regard to overhead wires, particularly if it be not proposed to erect these wires along public thoroughfares, and the local authorities' consent should in all cases be made subject to an appeal to the Board of Trade. At present such an appeal is only allowed in the single case of power companies' wires in rural districts, but in the case of all other companies' overhead wires, or with power companies in the case of overhead wires in urban districts and boroughs, there is no appeal whatever from the decision of the local authority, which is thus entitled to refuse its consent, or to attach unreasonable conditions thereto, without any further means of redress being available to these companies.

I would not have it thought that I am in any sense advocating a general use of overhead wires in place of underground cables. Both have their uses, and I think the more legitimate use of overhead wires in this country in the future will be for transmission lines across private land and at very much higher pressures than are used at present. A further consideration in the use of higher transmission pressures in this country is the practical impossibility, for many and various reasons, of erecting an entirely continuous overhead system, and most of our overhead lines must of necessity include a fair percentage of underground cables over sections of the route; therefore, whatever pressure may be adopted for the overhead system must also be suitable for use with underground cables. This leads to an examination of the high-voltage cable position. No very notable advance can be recorded since the laying of the extensive 20,000-volt three-phase cable system in this district some seven years ago, if we except a large system of 30,000-volt three-phase cables laid in Berlin about two years ago, following upon the experience obtained here. There are, I understand, some short lengths of 45,000-volt three-core three-phase cables in use in France, but, as far as I know, this is the highest pressure hitherto applied to three-core cables in commercial service, and it is difficult to foresee any possibility of exceeding this or even much lower pressures on a large scale on account of the heavy capacity currents and increased dielectric losses (which, it must not be overlooked, are continuous losses and independent of the load) which would be experienced at our usual frequencies. While with cables these losses increase in proportion to the square of the voltage, they are practically non-existent on overhead lines up to the limit of pressure at which corona effects take place. Another factor which largely determines the highest pressure that can economically be dealt with by an underground three-core cable is the maximum diameter and weight of cable which can be handled. Beyond this, it is necessary to resort to the use of three single-core cables at a greatly increased cost. At present I would set down the superior practical limit of pressure for three-core cables at not more than 40,000 volts, while there is no very obvious difficulty in constructing single-core lead-sheathed cables for three-phase work up to a working pressure of 50,000 volts per cable—that is, over 80,000 volts between phases with the neutral point earthed. Capacity currents and the copper and dielectric losses to which they give rise, and also sheath losses arising from the use of single-core cables, would not prove of such serious importance if these cables were used as an adjunct to our overhead lines in moderate lengths, distributed as usual at points along the route. I therefore apprehend no serious difficulty in increasing our overhead line pressures to anything between 60,000 and 80,000 volts if required.

Considering the importance of the subject, our knowledge of the science of cable design is still very incomplete, and although the general principles are fairly well established there is a remarkable dearth of technical data upon the properties of extra-high-tension cables. It is evident, for instance, that our thicknesses of insulation for extra-high-tension cables are in many cases unduly liberal and purely arbitrary. From what we know of potential gradients it is clear that a thickness of insulation

which will be correct for a large size of core, as, for instance, 0·25 sq. in., will not necessarily be correct for a smaller core, or for a round core against a clover-leaf core. The potential stresses will be relatively much greater in each of the last-mentioned cases, and yet we find that our engineering standards do not discriminate between such cases, but even allow thicker insulation on the larger sizes of cables compared with the smaller. It is no wonder that many of our paper cables frequently show factors of safety of 10, or even more, under test, and we might well refer to such as factors of ignorance. One cannot commend our lack of enterprise in research. While our cables undoubtedly rank as the best in the world, this position has been arrived at more as a result of careful attention to details of manufacture than by the application of scientific principles to design. Although there are happily signs of an awakened interest in this matter, still there appears hitherto to have been no co-ordinated efforts to place it upon a sure foundation, and yet I feel confident that a full investigation should enable a reduction to be made in our thicknesses of insulation, with a consequent saving of possibly anything from 10 to 25 per cent in the cost of extra-high-tension cables (6,000-volt and upwards) as the result of smaller overall diameters and the consequent cheapening of lead sheaths and armouring. This question is one for further investigation, but in the meantime we may take some comfort from the prospect that many of our existing cable systems are capable of being worked satisfactorily at much higher pressures than those for which they were originally laid down.

We may look to see some interesting developments in the utilization of waste gases within the next few years, both for the production of electricity and for town gas lighting. Use is already being made of coke-oven gas for town lighting in Germany and America, and, to come nearer home, the town of Middlesbrough has just entered into a contract with a firm of ironmasters to take the whole of their town gas supply from coke ovens; while another interesting experiment is that of the Birmingham Corporation, who have installed some coke ovens primarily to produce town gas and to dispose of the furnace coke produced as a by-product. Seeing that coke-oven gas should be obtainable at some figure below 6d. per 1,000 cubic feet, keen competition may be anticipated in those districts where such gas is available. The utilization of waste heat to its fullest extent for electrical purposes is only possible to those power companies with widely ramified networks, as much of it is only available at a distance from the large centres of population and chief points of power utilization; but by feeding into the main network at so many points remotely situated from the chief power stations considerable economies in the transmission system and its losses may be attained. Of course there are objections in the way of its rapid adoption, such as the limited quantities of waste heat usually available at any one plant, which would result in heavy capital cost for small stations; but when the use of by-product recovery ovens becomes more general it will doubtless in some cases be possible to concentrate the generating plant, the gas being piped from a number of near by-coking plants to a power station placed at some point favourably situated with respect to these sources of production. Another, and perhaps at first sight more serious, objection is the liability to interruptions from labour troubles and industrial depression, resulting in the shutting down of the producing plants. Some alternative method of keeping the station plants in operation, such as coal or oil firing, or producer or oil gas if gas engines are used, would be desirable at some of these stations, but not necessarily at all. This might in these cases be necessary to maintain the general scheme of distribution in the transmission system, although loads would obviously be very much diminished in such circumstances.

I do not think I need pursue these and other technical aspects of the problem of the centralization of power supply any further. The hindrances to our progress are by no means technical in character, and it is true that the world's achievements in electrical and mechanical engineering are far in advance of any of the possible requirements of this country for many years to come. When we learn, as from the States, of 30,000-kw. turbo-generators, of which seven are already under construction, the daily operation of high-voltage overhead transmission up to 140,000 volts and covering distances up to 240 miles, of 300,000-h.p. central-station developments and the electrification of some hundreds of miles of main-line railway, we need have no fear as to the ability of engineers to keep pace with the world's industrial demands. But for ourselves can we ever hope to maintain our position in the electrical engineering world if we are content to allow our electric supply industry to develop along its narrow way; indeed, have we not already lost too much ground? What training ground shall we offer the rising generation of British electrical engineers if we wish to take our part in the electrical development of our Empire overseas, and how shall our electrical manufacturers assume their proper place in the markets of the world when handicapped at home by a restricted market, which might easily be increased to many times its present proportions? Truly this question is more far-reaching than may appear at first sight. It is not my intention to discuss here the seemingly delicate question of how one may best reconcile the different and admittedly powerful interests which at present operate to the disadvantage of our industry, and I shall esteem my task well done if I but succeed in turning your thoughts in this direction.

WESTERN LOCAL SECTION: CHAIRMAN'S ADDRESS.

By H. FARADAY PROCTOR, Member.

(*Address delivered 27th October*, 1913.)

The Western Local Section has completed the first year of its existence, and it may be justly claimed that the result has been not only satisfactory, but that it has exceeded the expectations of the promoters. Last session four ordinary meetings were held for the reading or discussion of papers, etc., and the average attendance was 50; a result very creditable when due regard is given to the distances to be travelled by members attending our meetings.

In addition to the formal discussion of electrical matters, we have—by the kindness of their proprietors and managers —been able to pay visits to works of interest, and social intercourse has been promoted by the arrangements made for meeting together at dinner after completion of the business meetings.

Although much has been done in a short space of time to bring together the members of the Local Section and to promote further friendly relationship, the objects of the Section cannot be considered to have been fully achieved until we read and discuss at our meetings selections of the Papers approved by the Papers Committee for general reading and discussion before the Institution and the Local Sections. It must be borne in mind that the object of a Local Section is not confined to the welfare of its members; it is formed with the view of enabling its members to do that which may be of use to the Institution as a whole, and the electrical industry generally.

It is desirable, therefore, that papers read and discussed at the Local Sections should not be of local interest alone, but whatever their source they should as far as possible appeal to the greater body of members and be read and discussed before the Institution in London and at the various Local Sections.

The Committee have decided that for the present the holding of dinners after the ordinary meetings is to be discontinued. I regret this decision, as I feel that great good is likely to result, and has indeed already resulted, from such informal gatherings, because of the educational benefit which perhaps results more often from the smoke-room conversation than from the lecture-theatre conference; also because of that all-important factor, the promotion of good fellowship. In another association with which I am connected, viz. the Incorporated Municipal Electrical Association, it has been very fully realized that the backbone of the Association has been the friendly relationship that has been established between all grades of members and the large body of visitors who are attracted to the meetings, formal and otherwise. The marked superiority from this point of view of the gatherings in provincial towns over those held in London, resulting from the enforced intercourse at hours both late and early, is generally recognized and highly appreciated.

Advice is so often sought as to the proper course of training for an electrical engineer, that I may perhaps be pardoned for introducing a few comments upon that somewhat well-worn subject. I would suggest that it is desirable that the boy be first a gentleman; secondly, make him into a man; and thirdly, into an engineer. If he lacks the instincts of a gentleman he will not gain confidence; if he has not learned to behave like a man he will progress but slowly on his own initiative, and will require constant pushing; whilst if he has not the elementary principles of engineering ingrained, he will not get on even when pushed, and he will be for ever searching for complex solutions of simple problems and giving attention to details when broad principles are at stake.

I think it has been very generally admitted that the study of mechanical engineering is an essential preliminary to becoming an electrical engineer. Mechanical engineering is the broad foundation upon which electrical engineering is based. I fear, however, it is too often forgotten that mechanical engineering must itself have a foundation broad in proportion to the superstructure to be erected upon it, and capable of unlimited expansion in every direction. The young engineer does not know in what particular direction he may have to develop, and a broad intelligence based upon a sound general education is the best asset of an engineer, when combined with resourcefulness and an anxiety to understand and give due regard to all matters which pertain to the subject under consideration, although such may not strictly belong thereto.

The foregoing remarks perhaps apply more particularly to the student or young engineer rather than to my audience, who have already passed these stages and have made their way in the world.

Although I generally prefer English methods to those of our American cousins, among the many things we can learn from across the water is to keep well in mind the American definition of an engineer, viz. "a man who can do for one dollar that which any fool can do for two." The higher a man ascends the ladder the less time he has to devote to technicalities, and it is only by close attention to the commercial or financial side of business that men can hope to rise.

Although such is the more fascinating branch of our work, we, as business men, must to a considerable extent attend our Institution meetings and follow the work of the Institution with a view to its helping us in our business, and we must not look to the Institution merely as an interesting hobby.

Our Institution should, in my opinion, act as the advisers of all Government Departments in relation to matters of principle affecting the electrical industry, and should, where necessary, act as the arbitrators where differences arise between different branches of such industry.

Two subjects to which our Institution (through its Council and Committees) has recently been giving very close attention are Standardization and Co-operation.

I look upon standardization as the key to cheapness (without nuisliness), and co-operation as the key to standardization.

A great work has been undertaken by the Engineering Standards Committee, and great good has already resulted. I look forward with much pleasure to the time when the standardization of two-pin plugs and sockets, heavy current lamp-holders, and fuse terminals, will remove the most common source of the consumers' everyday little worries.

To promote our own efficiency, we should carry standardization throughout our office work. I believe few can realize the economy of time and freedom from worry that would result from anything approaching perfect method in office working. How few there are who can compile an efficient index to all the matters with which they have to deal in their daily business, and work to such an index. How few can file information on a proper system, and turn up the necessary item at the moment it is wanted.

The standardization of paper sizes would greatly facilitate such filing. Efforts have been made in this direction, and a little has been done—much more, however, might be done. For example, if our manufacturers would agree as to the size of paper to be used for their catalogues and correspondence a large amount of chaos on our bookshelves would be reduced to order, and by co-operation between the various societies the bulk of communications between engineers might be reduced to standard sizes, thereby very greatly facilitating reference. The compilation of a standard subject index carried to the necessary degree of finality, would also prove of great utility. The need for standardization, with the resultant economy, becomes the more urgent in electricity supply departments owing to the decreasing revenue derivable from the individual "lighting" consumers.

When the one-watt lamp came to the fore there was doubt in the minds of many as to its probable effect upon the sale of electricity. As another change similar in character—although less in extent—is about to be introduced, a few figures relating to the result of the former change may be of interest.

In 1909 a careful comparison was made of the consumption of electricity by a large number of consumers in Bristol who had installed one-watt lamps throughout their premises, with that of the same consumers when using carbon-filament lamps. Care was taken to ascertain that the results were directly comparable. The result (averaged) showed an economy to the consumer of 53·8 per cent. Since, however, the one-watt lamp represents an economy of about 68·5 per cent, it is evident that those consumers had on the average increased the candle-power installed by about 50 per cent. It is further interesting to note that after a lapse of four years the proportionate figures still hold good. From this it would appear that the average consumer has been educated up to require illumination 50 per cent in excess of that with which he was satisfied before the introduction of one-watt lamps.

With the advent of the "half-watt" lamp, I believe a similar result will be obtained. We may expect to see these lamps in use within the next month or two, but like their immediate predecessors they will not in the first instance be constructed of small candle-power for the pressures most usually found on supply mains.

Increased intensity of illumination will not be necessary, but lighting by electricity will, with the half-watt lamp, cost so small a sum that business premises will be more generously lighted, and in residences artistic effect will be given greater consideration, whilst less attention will be paid or necessitated as regards economy.

Since the light given by the half-watt lamp is very much whiter than that of the one-watt lamp, it should be excellent for the judging of colours. The lamps should, however, be kept well out of the direct line of vision, and indirect lighting should thus be encouraged to the utmost extent.

The "cost of electric light"—if I may be pardoned for using such an expression for the sake of brevity—will be so reduced as to put all competitive forms of illumination out of court; and the fact that electricity will henceforth be adopted for lighting all premises requiring artificial illumination (even if only for the sake of economy) will tend to keep the cable system satisfactorily loaded.

With the diminished revenue per consumer, the cost of making new connections will become a still more serious factor in the cost of supply. In Bristol the present cost of connecting premises adjoining the mains is £3 8s. (exclusive of the cost of the meter). Since the average revenue per connection derived from as many as 20 per cent of the lighting consumers amounts to only 35s. per annum, the importance of this item is evident. It is also obvious that the uses of electricity for purposes other than lighting must be developed to their utmost; otherwise the lighting consumer may become a serious drag upon the undertakings.

Another matter of serious import, which the lighting engineer should bear well in mind, is the probable adoption of a Daylight Saving Bill. The advantages to the general public resulting from such a measure appear to me to outweigh so far the disadvantages, that I cannot realize why the suppliers of artificial illumination have been allowed up to the present to enjoy their existing load factor.

Electric cooking has developed wonderfully during the last year or two, and with the standardization of details will rapidly displace its rivals.

I believe that the satisfactory heating of water for domestic uses will soon remove what is now the greatest obstacle advanced against the introduction of electric cooking. To get rapid and highly efficient water heating, it will, I consider, be necessary to use immersion heaters, probably applying the heating element direct to the water, and avoiding the risk or possibility of shock by utilizing the resistance of two columns of water—one on the supply side and the other on the delivery side of the heating appliance, the supply and delivery extremities of these columns of water most remote from the heating elements being electrically short-circuited and earthed. The elements must in such an appliance be either self-cleaning or arranged so that they may be very readily cleaned in order to avoid trouble due to lime or other deposits. For the probable solution of the domestic hot-water problem I look to such appliances arranged alternatively for rapid water heating, the energy being supplied at the usual heating tariff, and for continuous use at a fixed annual kilowatt charge.

Several years ago it was prophesied that we should have to look to the development of the use of electricity for

power purposes for our revenue. That prophecy has been very amply proved. For example, in this city the power consumption has increased 8 times as rapidly as the lighting consumption during the last 10 years. During the next two years this ratio will be doubled.

I have endeavoured to condense my remarks as much as possible, and have merely drawn attention to the urgent necessity of expanding the uses and demand for electrical energy, also of co-operation and standardization in order to secure such expansion by furthering economy and efficiency, and finally of so training the electrical engineer that he will be resourceful himself and inspire confidence in others; for it is to the "business getting" department that we must look for the bulk of our progress. We must bear in mind that an article is more easily made, than sold at a profit.

MANCHESTER LOCAL SECTION: CHAIRMAN'S ADDRESS.

THE VOCATION OF AN ELECTRICAL ENGINEER.

By Professor E. W. Marchant, D.Sc., Member.

(*Address delivered 4th November*, 1913.)

The proper education and training of an engineer have been discussed at such length and so frequently within recent years that I feel a certain reluctance in taking for the subject of my address this evening one which bears, or might appear to bear, any direct relation with that question. It seems to me, however, that the time has come when it might be advantageous to look round at the vocation of the electrical engineer to see what he has accomplished and to make an attempt to determine the place that he should fill in the industrial world, the steps which may appear possible to improve his status, and the reward that he should receive for the long and arduous training through which he has to pass before he can be regarded as a fully qualified member of his profession.

My chief reason for discussing this subject is that the electrical engineer to-day is a very specialized person. Electrical engineering has developed so rapidly and in so many directions that it is now impossible for one man to keep in touch with what is happening in all the branches of activity in which electrical engineers are employed. Each man becomes obsessed, and very rightly so, with the work for which he is responsible; he busies himself in becoming acquainted with the technical development of his subject, and there is, I think, some danger that the "human" aspect of his profession may become forgotten and may be neglected.

In dealing with this subject it is my intention to discuss the possibilities and prospects of electrical engineering for the individual engineer, and not so much the development of electrical engineering (that has been dealt with already by abler hands than mine); and though the two subjects are necessarily intimately related, there are certain aspects of what I may call the "human" side of the question which I think deserve special consideration.

It is also opportune at this time to discuss the subject, because the Institution has recently organized a system of examinations to test the quality of the candidates who wish to join its membership. In putting this scheme into operation it is following the example that has already been set by the Institution of Civil Engineers; and, in passing, may I express the hope that some of the things that have come about in connection with those examinations may not creep into the examination scheme of our Institution. I refer particularly to the risk of people cramming for the examination in order to get through, without going through a course of training and getting a real knowledge of the subject of which the examination is intended to provide a test. The examination scheme has been drawn up (with the same intention, I presume, as all examination schemes have been devised) to test the knowledge of the candidate, and to avoid, as far as may be possible, the prospective member cramming for it. Those who have had experience of this work know how difficult it is to achieve this end, especially after the examination has been in operation some time, and it is the hope of a good many of those engaged in educational work that besides showing ability to pass an examination the prospective candidate should also give evidence of having passed through a recognized course of instruction in some approved institution.

The examination is a step in the direction of attempting to provide that members of the Institution shall really understand the principles underlying the work in which they are engaged, that their work should not be done merely by rule of thumb, and that evidence should be given of the capacity to think. To produce men of this kind is the object of all the universities and technical colleges of higher grade. That this has not been recognized more generally is possibly to some extent the fault of the institutions concerned, but it is to be hoped that the result of the establishment of the new examination scheme may lead to a closer connection between the Institution and the chief training colleges—a result which should prove of much ultimate advantage to both.

The electrical engineer, like every other member of the civilized community, has to take a place in the social structure; his position must depend (and here I do not mean his position in any narrow sense) on his recognition of the position his labours take in the work of the world. On the recognition of this fact by the world at large depends his future, not only from the point of view of influence, but also financially, and it is from this standpoint that I wish this evening to take a brief survey of his position.

I propose in the first place to discuss the prospects and opportunities which seem to me likely to occur in the various branches of work in which electrical engineers are engaged at the present time. The discussion is not in-

tended to be exhaustive. It will be impossible to find time to touch upon many branches of work in which members of this Institution are actively employed, but I hope that what I say may draw some attention to this most important aspect of the life of an electrical engineer.

Central-station Engineers.

The construction and supervision of stations for the supply of electric power must always provide occupation for a considerable proportion of electrical engineers. The running of a small station, *i.e.* the mere keeping of the engines and dynamos in order, is work which requires a comparatively small amount of general knowledge of electrical engineering principles. In America the running of such stations is largely in the hands of men who have had no thorough training in the principles of their profession; in some cases they are really "engine drivers" in the narrowest sense. Central-station engineers in England have been trained very differently, and I believe the result has been most beneficial to the development of electrical power supply.

The ideal central-station engineer is one who must possess a great variety of qualities; not only must he be a good engineer, but also a good man of business. In the opinion of many the latter qualification is the more important; but it is mere platitude to say that if this qualification is not combined with a sound knowledge of engineering principles, if the engineer is not able to keep in touch with all the most recent developments, his station will soon get out of date.

The central-station engineer is destined in the future to take a still more important place in the life of the community than he occupies at present. The use of electrical energy for lighting and domestic purposes has progressed, some think, too slowly, but it is significant that no one who has ever experienced the advantages which a supply of electrical energy gives, ever wishes to go back to any other system. Without looking to any of the more startling developments to which Dr. Ferranti has done so much to draw attention, there is an enormous field for the central-station engineer.

The remuneration offered, however, to those taking up this work is quite inadequate to its responsibility. Besides direct evidence, which must be known to all, I should like to draw attention to one or two facts which bear on this point and which are of importance. It is a matter of common knowledge that successful central-station engineers, in all but the largest cities, have in many cases forsaken their positions to take up consulting work, and are retained by their former employers as consulting engineers. It would surely be better worth the while of most central-station authorities to have at the head of affairs men of experience who would be able to do all the necessary work for the central station without outside advisers being called in. If this is to happen, it must be made worth the while of the central-station engineer. It is significant also that the salary offered to those who wish to enter some of the power companies has increased to a most marked extent during the last year or two, due to the fact that the supply of men has rapidly fallen off. I heard the other day of a case in the West of England where an engineer who years ago had dozens of men on his books who were anxious to get into central-station work, now has none. The list of vacant positions in the electrical journal advertisements is more than twice as long as that of men wanting employment. This is a very healthy sign and is a hopeful augury for those who have started in this profession.

If the office of electrical engineer to a town or city is to become one of increasing honour and importance, it is essential that it should be filled by thoroughly trained men. I do not wish here to lay great stress on college education, although that in the view of educationists is an essential element in the training of such people; but they should be persons of good general knowledge and high intelligence, in order that, when the time comes, they should be competent to assume the greater responsibilities which will rest upon them. To attract such men it is essential that these positions should be made financially remunerative. One cannot expect a man of promise to be content to spend ten years of his life preparing for a profession which in the end will yield no adequate return for his expenditure of time and money. We have heard a good deal lately of the poor payment of members of the medical profession. A panel doctor with 1,200 patients receives a fixed income of at least £360 a year, and this may be regarded as a minimum salary for a qualified medical practitioner to-day. The training through which an electrical engineer engaged in central-station work now has to pass, with three years at college and three or more years at works, is as exacting as that which a doctor receives. Yet there is a very large proportion of central-station engineers in this country, and I am not speaking here of people in positions of great responsibility, who would be glad to regard the above as their minimum salary. The electrical engineer of a town can do as much (if not more) for the health of the community as any other person in it; he can brighten the homes of the people, make them hygienically better places to live in, he can supply the power to enable them to cook their food, and in combination with the gas engineer he can get rid of nearly all the smoke and dirt which hitherto have made large towns such objectionable places to live in. Surely such a man, whose work affects the life of the whole community, deserves as ample a recompense as the man who treats a limited fraction of its members.

Electric Railways.

The electrification of railways seems likely to be the direction in which the most important developments will take place during the next few years. The railway companies to-day are in a better position financially than they have been for some years, and the competition of tramways and motor-omnibuses makes it imperative that the electrification of suburban lines should be carried out if the railways are to retain their local traffic.

The results obtained by the Lancashire and Yorkshire Railway, the London, Brighton and South Coast Railway, and by the Metropolitan District Railway, are outstanding examples of what electrification can achieve. The electrical engineer who intends to go in for railway work has apparently a great opportunity. The risk, from the standpoint of the electrical engineer, is that the railway man will regard the railway side of the problem as the fundamental one, and the use of electricity as a side issue. In a way this is true, and it behoves the electrical engineer

who looks on this work as his future vocation to recognize the fact and to equip himself with a thorough knowledge of railway conditions.

Take two obvious examples: The arrangement of a schedule of trains for a suburban line is a problem of some mathematical complexity; the estimation of the power taken by an electric locomotive on a given line of road entails a large amount of detailed calculation and a thorough knowledge of mechanical principles.

For this class of work the necessity for a good general engineering training is evident; but, given this essential training, the field of the electrical engineer in railway work becomes very wide—he must concern himself with the erection and maintenance of central stations and sub-stations for the supply of electrical energy, he has to design and maintain a complete system of feeders and overhead conductors, and finally, he has to design and supervise the running of the electrical equipment of the trains. But the electrical engineer is not responsible solely for the supply of motive power, for in a modern system in cold or tropical climates provision must be made for the heating or cooling of the trains, as well as for providing a supply of electric light. As electric railways progress it seems certain that the position of mechanical engineer to a railway will be filled by an electrical engineer, and if the success that has attended the promotion of an engineer to the position of general manager of a railway has the effect one may reasonably anticipate, the electrical engineer may regard as a legitimate aspiration that he should be called on to fill this great administrative position.

Manufacturing.

The greater number of men with whom the staffs of universities and technical colleges have to deal find their way to the manufacturing firms, and a considerable proportion of the membership of the Institution is engaged in the design and manufacture of electrical machinery and apparatus. The equipment of the engineer intending to take a responsible position with a large firm has to be, from the technical standpoint, more complete and thorough than that required in any other branch of electrical engineering. If the practice that has been followed in Germany, and to a certain extent in America, is to come into operation here, the manufacturing firms will supply consulting engineers who will advise as to the character of the plant that is to be used in connection with any large scheme of power supply. Such positions involve great responsibility, and require technical knowledge of the highest order to fill them adequately; men of wide experience both in manufacturing and in constructional engineering are necessary. Let us consider now what likelihood there is, under present conditions, of such men becoming available.

It is easy enough for men who have had a college training to enter works at the present time; most manufacturers seem only too anxious to obtain their services, and a living wage in many cases is paid from the start, but the number of openings that are better paid is much less. There is a great gulf fixed between the men who are "just" on the staff and those in leading positions in a works, and in the long interval that must elapse before one of the first class become eligible for the higher positions there is a period of great difficulty for most engineers, in which the best men feel that they are wasting their time. In some cases men have left the profession who would otherwise have proved themselves a valuable addition to it. The main point that I would urge is that this condition is a discouragement to many able men who might otherwise have entered electrical engineering and have done much to advance it.

I was discussing this matter the other day with a man in a good position with one of the best-known electrical engineering firms in the country, and he gave me as his opinion, that in his firm a man of initiative and energy might hope, by the time he had reached, say, the age of 35, to receive a salary of £300 a year; of course there are some who would receive less, and a few who would receive a good deal more, but I think all will agree that this prospect is not such as to attract into electrical engineering the bright minds and keen intelligences which it is so essential for the welfare of the industry should be attracted.

Even in the early days of an engineer's career in a works his remuneration is less than it should be. I know of one firm who offer a college-trained man who has served his apprenticeship 30s. a week to start with, whilst a mechanic who has served his time can get 50s. What is the result? The only men who go to this firm are those who want to get a practical experience and who are on the look-out for a better post from the start. The best men leave almost at once; the men who are not worth much remain.

The criticism I am making does not apply to some works; it does not apply, as far as I am able to judge, to American works, though the same difficulties arise in the works of many German firms. The manufacturers have been in a very strong position in the past, because the supply of trained men on which they could draw has been large; now the conditions are changing, and I would strongly urge that in order to attract the best type of persons into the profession of electrical engineering the standard of remuneration for technical men must be advanced. The expense involved is not large compared with that necessitated by an increase in pay of the workmen, since the number of such people engaged in manufacture is relatively small; surely it is to people of this type that a manufacturer must look far more than to any other for the progress and advance of his business, and it is of the greatest importance to him to ensure that such people shall be forthcoming in the future.

The manufacturers have been hard put to it during the past ten years. The keenness of competition and the excess of the output over the demand for electrical apparatus have not tended to make the business of electrical manufacture remunerative; under such circumstances it is useless to urge the principles which I have quoted; now, I venture to think, the conditions are changing, demand is overtaking supply, and the prospects of the manufacturer to-day, I believe, are better than they have been at any time during the last decade. I hope, therefore, that it is a suitable time at which to urge this matter, and to lay stress on the necessity of ensuring that the prospects of those entering an electrical engineering works shall be at least as good as those in any other branch of engineering practice.

Telegraphy.

The branch of electrical engineering which originally gave its name to this Institution forms to-day a comparatively small part of it, though possibly the proportion of engineers interested in telephony and telegraphy is considerably larger than many of the members of this Local Section would imagine.

The operating branches of telegraphy and telephony are under the control of the Government, and those engineers engaged in what the Germans call "*Schwachstromtechnik*" possess all the advantages and disadvantages of Government service. As in other branches of the Government service the position of its engineers is not as satisfactory as it might be, and the plea which has recently been made by one of the leading electrical journals for a fuller recognition of the working branch will find an echo in the minds of all those engaged in this work. It is to be hoped that the higher administrative positions in this service will in the future be more open than they appear to be at present to those who have a thorough knowledge of the technique of telegraphy and telephony.

It is only by a complete co-ordination of the technical and administrative sides of this undertaking that the greatest economy and efficiency can be reached, if that end is to be attained the electrical engineer must be ready and fully equipped for administrative work. Here, again, it is the right type of man that is wanted. To get the right kind of person the engineering side of telegraph and telephone engineering must be made attractive enough to ensure that the most able men shall think it worth while to become telegraph engineers. In this connection it will be within the memory of all that an engineer, for whose reputation all who know his work have the highest respect, was recently prominently before the public in connection with the Marconi affair. It was a matter for comment that this man was spoken of frequently in Parliament and elsewhere as a clerk, no doubt partly for political reasons, but mainly because it was the view of the people who spoke, that a man receiving such a salary as was mentioned could not hold the position of a responsible engineer but must be in one of inferior responsibility.

The case for improved conditions in the telegraph service is overwhelming. Some of those engaged in the manufacture of telegraph and telephone material have recognized this, and offer advantages which are unequalled by any other electrical firms. The Government telegraph service now appears, however, to adopt a different policy. The importance of the service of the telegraph and telephone to the community to-day demands that those engineers engaged in its direction shall receive recognition at least equal to that given to those responsible for any of the other great national services.

Electrochemical Engineering.

The application of electrical energy to chemical manufacture has made great strides during the last decade, and the price at which electrical energy can now be sold makes it evident that electrochemical processes will come even more extensively into use, not only for the manufacture of alkalis, carbides, and the like, but also for smelting iron and steel. The questions involved in the application of electrical energy to purposes of this kind are essentially engineering problems. The chemical and thermal processes of most of these operations are well known, and the application of them involves the design and operation of suitable furnaces and machinery which will enable the manufacture to be carried out on a large scale. Electrical engineers should find a considerable field for their activities in this direction, and one of the advantages this branch of engineering possesses is that it is likely to be rapidly progressive as the cost of electrical energy decreases. It is to be hoped that this work will not be left in the hands of those more directly concerned with chemical problems, as progress is much more likely to be rapid if the mechanical design of the plant is sound. This fact has been illustrated already in electrical engineering of the more mechanical kind, where the application of electrical machines has undoubtedly been retarded by the faulty mechanical construction of many of the early types of dynamos and motors. The percentage of electrical engineers in the Institution interested in electrochemical engineering is very difficult to estimate; it is small at present, and is not destined to become as large as that engaged in the manufacture of electrical machinery, but there seems little doubt that there will be a rapid growth in this industry. The training for such an engineer should be a thorough engineering training, combined with a good knowledge of chemistry, a curriculum which is provided in most of the larger technical schools and colleges. It remains for the users of these processes to employ the raw material that is being produced.

Consulting Engineers.

The consulting engineer has been consigned by some people to a speedy end, as far as electrical work is concerned, his place being taken, as has already been suggested, by engineers employed by large firms. It will, however, be a long time before the consulting engineer finds himself without occupation. Consulting engineering as a vocation can, however, hardly come within the scope of this brief survey, since a consulting engineer is necessarily a man who has had experience in one of the branches of engineering to which reference has already been made. The vocation of consulting engineer is one of great distinction, but the number of people who act as consulting engineers must always be comparatively small, and the vocation is one which must be regarded as supplementary to the branches of practical work to which I have drawn attention.

I have made some attempt to classify the membership of the Institution with a view to finding the proportion engaged in each branch of work. The classification is very incomplete, and has been applied to only one class, namely, Members. The thing that has surprised me has been the apparently large proportion of men engaged in the business of the supply of electrical power who are members of this Institution. That, of course, is the greatest work at the present time, but it is one which will not, I believe, tend to increase very rapidly as an employment for engineers. The tendency to-day is towards large power stations and long transmission lines; anyone who has seen the large power stations in Canada and the States, especially those operated by water, cannot but have been impressed by the very small number of engineers required in the case of stations of, say, 50,000 kw. capacity.

The first conclusion reached from this classification is that there must be a large number of electrical engineers engaged in manufacturing and constructional work who are not members of this body. These men are of great value to an Institution such as ours, because it is they who are really in the forefront of discovery; they know all about a new machine and a new design long before the operating engineer comes across it. I do not think the Institution can be regarded as being to blame for this, as the papers read during recent years have dealt in no small degree with subjects which should interest designers, and I hope an effort will be made to bring men of this type into the ranks, as they cannot fail to strengthen the membership.

A consideration of the opportunities which offer themselves at the present time makes it clear that the electrical engineer of the future must be able to take a broad view of his profession, whether he be engaged in central-station work, manufacture, telegraphs, railways, or as a consultant, and he must be able to see all sides of a question. He must be able to solve new problems along sound lines. If men of this kind are to be available as electrical engineers, it is essential that the best type of person must enter the profession. Much depends on this in the future. If the electrical engineer does not look to his laurels, there is a risk that the "plums" of the profession may fall into other hands; and unless employers on the other hand are prepared to offer adequate salaries, they run the risk of failing to secure the best people on their staffs. The position to-day is critical, and on the attitude of the industry to its engineers depends the future of the electrical engineer. The magnitude of the tasks that lie before him, the complexity of the problems he has to solve, the greatness of the results he can achieve, are unequalled in any other calling. For the best results the best men should be got, and whether the best men take up electrical engineering depends entirely, or almost entirety, on whether it is made worth their while to do so.

As far as one outside the industrial world can judge, the prospects of the electrical engineering industry at the present time are exceedingly good. The supply stations have recovered from the set-back which they received when the metal filament lamp was introduced, and the fact that electric light on the basis of the cost of illumination, with a supply of energy at rates such as exist in Liverpool and Manchester, is actually cheaper than lighting by gas, is becoming generally recognized.

The use of electricity for power is coming more and more rapidly into operation. The electrification of railways seems at last to be making great strides forward, and we hear of schemes from nearly all the leading railways of this country for the electrification of considerable portions of their track.

The electrification of cotton and wool mills, and the use of the electric drive for rolling mills and for factory work of all kinds are progressing apace. The only cloud on the horizon is the motor-omnibus, and it is not unlikely that even this vehicle may become sooner or later a source of load for the power stations. Electrochemistry for manufacture is making rapid strides, while wireless telegraphy is in the air and has stimulated the cable companies to great efforts in improving communication.

The prospect for electrical engineering then is good; it is even better if one takes into account the openings that are available for those willing to go abroad. It behoves the electrical engineer, then, to make use of his opportunities and to see to it, as far as lies in his power, that there may be great difficulty in obtaining really competent and well-trained electrical engineers at too low a salary. This sentiment, no doubt, appeals to all members of this Institution, and I lay stress on it, not for the very obvious reason that we should all like to have a little more money, but because it must be acknowledged that the income derived at the present day by most electrical engineers from their profession is generally not high enough, considering the importance of the work they have to perform.

The interest and fascination of the study of electrical science have attracted into the ranks of electrical engineering many who from the point of view of making money would have taken up some other branch of work, but that fascination can only exercise an influence in the comparatively small number of cases in which the requirements of life are a matter of secondary importance. There is no profession of which it can be said that the persons in it have a greater enthusiasm for its progress and a greater faith in its ultimate triumph. Without unduly lauding our own Institution or the corresponding American Institute, I think it can be said that the general interest shown by all members in a paper of really first-rate importance is not exceeded by any other engineering institution.

This is a great asset to any industry and to any science; without such interest and such enthusiasm progress is impossible. But that is not all. It is essential to the welfare of any profession that it should attract the best type of person, the man of good training, broad mind, and wide outlook. It must be made evident, therefore, that electrical engineering offers at least as great an opportunity as any other career. This fact should be remembered by those in the higher positions who control the remuneration of junior men, and especially by employers in the large companies, which now direct so large a proportion of the manufacturing industry. If the positions of responsible electrical engineers are improved, it will be a good day not only for the firms concerned but for electrical engineering generally. The matter is one of supply and demand: the supply hitherto has been ample, the demand meagre; now, demand is overtaking supply, and the necessary consequence of an increased demand is either a worse quality of product or a higher price.

It is to be hoped that the members of this Institution who have it in their power will see that it is the latter alternative that is chosen by the electrical engineering industry.

YORKSHIRE LOCAL SECTION: CHAIRMAN'S ADDRESS.

By W. B. Woodhouse, Member.

(Address delivered 6th November, 1913.)

Engineering covers so wide a field that there is a natural tendency for engineers to segregate, and, in the pursuit of their own particular branch of the industry, to overlook the work done by those engaged in other branches. This has been in the past particularly true of the problems relating to the utilization of coal, and therefore a broad consideration of these problems may be of value. The consideration naturally falls in two parts: the extraction from coal of its valuable properties, and the distribution of its heat energy.

The valuable properties and constituents of coal are many; in addition to the heat derived from its combustion there may be obtained ammonia, tar, pitch, creosote, benzol, cyanides, sulphur compounds, and other products. The value of these chemical products is enormous, and the process of burning coal in its raw state wastes them entirely. To burn raw coal is a process of the same primitive nature as that adopted by Lamb's Chinaman for the production of roast pig, and to continue the analogy, it is time that we discovered the needlessness of firing the house for the sake of the crackling.

The most inefficient use made of coal is to burn it in the domestic fireplace; not only is some 70 to 80 per cent of the heat lost, but the pall of smoke which hangs over our towns as a consequence of the practice is actively injurious to health and agriculture.

When consumed under steam boilers and utilized to produce steam power, the case is little better; the best modern practice accounts for only 15 per cent of the heat energy, and the average practice for not more than one-half of this.

Due primarily to the work of Sir Charles Parsons, there has been notable progress made in the utilization of steam in recent years, and if coal be regarded merely as a fuel, the present utilization is approaching the limits of possible use; future progress must be on broader lines. The heat value of a ton of coal is some 30 million heat units. If the coal is burnt to produce electricity, there its value ends; if it is distilled in the manner adopted by gas engineers some 20 per cent of the heat energy is made available in the gas produced, and some 60 per cent left in the resultant coke, but in addition tar, ammonia, and other valuable products are released, and the sale of these makes a substantial entry on the debit side of the balance sheets.

As an example of the value of the process of carbonization of coal as carried on by gas-works, the published figures of the costs and receipts of a large gas works are instructive. The cost of manufacture, excluding capital charges, amounts to 22·89d. per 1,000 cubic feet of gas made. The receipts consist of:—

Gas	...	... 25·55d. per 1,000 cubic feet of gas
Coke	...	... 7·46d. ,, ,, ,,
Tar	...	... 2·03d. ,, ,, ,,
Ammonia		... 2·57d. ,, ,, ,,

These figures are sufficient evidence of the value of the process adopted. While this method of utilizing coal is greatly in advance of the practice of burning which accounts for the greater part of the coal consumed in this country, it is yet open to criticism; the gas engineer's primary object is the production of gas, and the process of distillation adopted while giving a maximum yield of gas does not make the best possible use of the coal. A variation of the temperature of carbonization is accompanied by a variation of the quantity and illuminating properties of the gas, of the production of ammonia, and of the properties of the hydrocarbons produced; and in view of the demands for the various coal products, it is obvious that there may be room for variation of the method of carbonization dependent on the relative values of and markets for the various products.

For example, there can be no doubt that at present the most efficient means of heating dwelling-houses is by means of a central heating apparatus replacing all the open fires, but this method is so contrary to the prejudices of the people that its adoption makes only slow progress, and in the meantime much has been heard of the advantages of burning a smokeless fuel, a semi-coke from which the chemical products, if they may be so called, have been taken away. The production of such a fuel involves carbonization at a much lower temperature than that of a gas retort, and the yield of certain products of distillation is increased.

The development of the principle of carbonization on broader lines has, however, come from the needs of the iron and steel trades, the largest users of coke. Furnace and foundry coke in the past was produced in bee-hive ovens, wastefully so far as utilizing the chemical products of the coal, and not particularly economically in producing coke.

The evolution of the by-product oven has, however, changed all this, and now in addition to producing coke for the ironmaster, the mining engineer produces gas, tar, ammonia, benzol, and other valuable substances, and so makes efficient use of the raw material, including incidentally a greater yield of coke.

The method adopted for distributing the energy of the coal will determine the particular process of carbonization to be used; but whatever process is adopted for the extraction of the valuable products from coal, that process can only be carried on economically on a large scale, and therefore the distribution of coal energy, whether in the form of solid fuel, gas, or electricity, must be on a large scale also. In other words the essential centralization of coal-carbonizing plants implies distribution of light, heat, and power over large areas and in large quantities, and under such conditions electrical means are by far the most economical.

Up to the present time electricity has been generated in central stations by methods akin to those adopted by individual power users, only more economically due to the advantages of centralization. That is to say, a public supply is merely a co-operation of users to take advantage of certain economies.

The next step forward is a further co-operation of the electricity supply undertakings with other processes, involving the use of coal. And the first example in Yorkshire of co-operation of this kind has recently been set to work at the coke ovens of the Old Silkstone Collieries in conjunction with the Yorkshire Electric Power Company. In this case the surplus gas from the coke ovens produces continuously day and night some 2,000 kilowatts of power, which the power company supply to their customers by working the station in conjunction with their general system. Such an arrangement as this is only possible on a large scale, but its economic advantages are obvious.

The manner in which coal is used to supply the demand for light, heat, and power, is dependent very largely on the methods of distribution available. Of the various methods the most successful must be ultimately that which is cheapest and most convenient, convenience carrying with it a due regard to healthfulness.

So long as no other means of heating and cooking were available, the distribution of coal to dwelling-houses was inevitable, but with a recognition of the folly of burning coal the alternative of burning coke or smokeless fuel (semi-coke) must increase, and if no other means of distributing energy were available would eventually entirely alter the present practice.

Now regarding only convenience and cleanliness, the use of gas presents advantages over that of coke, and the use of electricity over both. Domestic labour must be reduced, the utmost cleanliness must be established, and the healthiest conditions maintained. On these three points electricity is superior as a means of distribution. But in regarding cost one must recognize that the production of coke or semi-coke will be in the future enormously increased, and unless the demand increases with production its price will fall to such a point that in many cases its cheapness will outweigh the advantages of its competitors.

Not to look too far ahead, then, one may safely conclude that a demand will exist for solid fuel in dwelling-houses, marking a transition stage from coal to electricity. In the same way dependent on the laws of supply and demand, coal gas and producer gas will find a place in the general scheme of distribution. But as gas, coke, oil, and tar can all be used as fuel for the production of electricity on scientific lines, there can be little doubt that domestic needs will be principally met by the supply of electricity.

For power purposes electricity generated in the same primitive manner adopted by the individual power user is steadily displacing all other methods, and this because in addition to its convenience it can be supplied more cheaply than power can be produced in isolated plants. That it can be so supplied is due to the advantages of centralization already mentioned, and if we add the advantages of co-operation with other processes in extracting the valuable properties from coal, the advantages become enormously increased.

In the future distribution of energy electricity must take a large and, I believe, predominating part. But its progress is not solely controlled by engineering and chemical problems such as those to which I have referred; one must also consider the legislative and financial conditions under which the supply of electricity must be developed. Technical difficulties may be overcome by individuals, but legislative obstacles will only be removed if the electrical industry moves the public to call for it.

The first step to be taken is to encourage a better understanding between the State departments, the municipalities, the power companies, and others engaged in the business.

The legislation affecting the public supply of electricity has not been helpful in development on broad lines, and State control has generally speaking been repressive rather than helpful. The economical development of our natural resources deserves and acquires a helping hand, and the utilization of coal might well be regarded as equally worthy of State support as, say, the London Docks.

The veto of local authorities, the power of purchase granted by the Electric Lighting Acts, and the general influence of municipal trading, have not made for progress.

As a case in point, the fear in municipal minds of the effect of the competition of electricity on their gas undertakings may be instanced. Anyone familiar with the development of electric supply in this country knows that this has been one of the most potent reasons for the acquisition of electric lighting powers by local authorities, and where both gas and electricity supply are controlled by the local authority future developments may anticipate similar opposition. Broadly speaking, the local authorities are afraid of the power companies, the gas engineers of their electrical brethren, and so on all round. The time has come for this partisan spirit to be swept away and for the problem to be dealt with on broader lines altogether: unless this is done progress must lag and the country suffer.

State control should aim at assisting those engaged in the industry to obtain the best results. Municipal spirit and local pride should not deny the advantages of new developments as they arise to their ratepayers, nor a share of the benefits to those individuals who by their enterprise develop more efficient conditions. Private enterprise, while best fitted to break new ground, would yet be assisted by the financial support which could be given by the State and the municipalities.

Where municipal trading is indulged in directly, the advantages of cheap money, such as municipalities can raise on the security of the rates, are great, but the moral obligation not to speculate with such money is great also, and the natural effect of such trading is to discourage new developments which might depreciate undertakings already financed with ratepayers' money.

The best results can probably be obtained by a compromise; let private enterprise continue to develop improved methods, and if the municipalities desire to exercise some control of the developments, then let them assist in the finance.

Some years ago, in addressing this Institution, I suggested that municipalities might with advantage to all parties subscribe to debenture issues of public-utility companies. The steadying effect of municipal capital would yet not act as a brake, and with their financial interest some measure of control would naturally be exercised.

In a public supply a service at the lowest rates can only be given if money is cheap; and cheap money demands adequate security. If the investor can be assured of State control of public utilities, coupled with reasonable protection, just regulations, and a measure of financial support, we need have no fears of the future progress of electricity supply in this country.

SCOTTISH LOCAL SECTION: CHAIRMAN'S ADDRESS.

By J. A. ROBERTSON, Member.

(*Address delivered 11th November*, 1913.)

Before commencing my address as Chairman of this Local Section I should like to refer to the ceremony which took place in this city a few weeks ago, when a statue was unveiled to the memory of Lord Kelvin on a site adjoining the University. I need scarcely remind you of Lord Kelvin's connection with our Institution. He was one of the original founders of the parent Institution, and was President no less than three times. He did this Section the honour of becoming its first Chairman, and again occupied that position in the session of 1906–7 up to within a few months of his death. The members of this Institution require no memorial to remind them of the great work that he did for us, not only by his scientific discoveries in the laws relating to magnetism and electricity, but also by inventing that long series of standard electrical instruments which perhaps have done more than anything else to make electricity the precise and accurate application of science that it is to-day. It is well, however, that the citizens of Glasgow should have erected a memorial which will constantly bring before them the association of Lord Kelvin with their city, and the great work which he accomplished, not only for electrical science, but also for navigation and in many other directions.

We are passing through a period of extremely rapid development in the multifarious applications of electricity, and questions which appeared but a few years ago to be in the domain of pure speculation are now claiming attention as practical problems waiting for solution in the near future.

The efficient utilization of the natural fuel resources of the country by concentrating the manufacture of power in large central stations and transmitting over areas extending to hundreds of square miles, the abolition of the smoke clouds which disfigure and pollute our cities and towns, the electrification of our railway system, the possibility of replacing existing systems of motor transit in our streets by cheaper, cleaner, and safer methods, the application of electricity on a large scale to chemical processes, and its employment in the production of steel and iron, these are some of the questions which will claim attention from the electrical engineer within the next few years.

I do not propose to-night to take up any of these problems in detail, and should like with your permission to discuss some recent developments which have brought these questions to the front, to indicate the existing limitations to further advancement, and to consider in what direction future progress lies.

The possibility of concentrating power generation in large central stations is primarily due to two causes:—First, the improvements made in the steam turbine during recent years; second, the development of high-tension multi-phase systems of transmission.

We have had the steam turbine with us for many years, and although recent developments have been chiefly in what is known as the impulse type, yet it will be generally admitted that we owe to Sir Charles Parsons the credit for giving us the greatest advance in prime-movers we have ever known. The turbine is free from nearly all the limitations of the reciprocating steam engine, and combines simplicity of construction with economy of operation. Its efficiency is high compared with the steam engine and fairly uniform over a wide range of load. It requires little attention, and can make long continuous runs under severe fluctuations of load, while its overload capacity is greater than that of any other prime-mover. A modern power station equipped with water-tube boilers and steam turbines represents practically the limit of economy so far as present knowledge goes. A 5,000-kw. turbo-generator will deliver a unit of electricity at its terminals for about $13\frac{1}{4}$ lb. of steam at 550° F. with 28-in. vacuum at the condenser; while a 10,000-kw. set may bring the figure down to $12\frac{1}{2}$ lb. This appears to be the limit of economy in the existing state of progress, and it is possible to supply energy from central stations under these conditions at rates cheaper than any private user could generate it for himself. But the fact remains that even in the best modern power station equipped with the latest type of water-tube boilers and laid out to secure the maximum economy by the use of economizers and superheaters, and with every care taken to prevent unnecessary loss, we are only able to secure an overall thermal efficiency in the station of about 15 per cent. That is to say in converting the energy stored up in the fuel into electricity, from the time it enters the boiler fire until it is delivered at the switchboard, we lose 85 per cent in the process of conversion; 30 per cent of this loss may be attributed to the boiler-house, in the form of heat lost in the chimney, radiation from boilers and piping, and leakage in the boiler settings and flues. In the turbine 5 per cent will be absorbed by friction and radiation, 4 per cent in generator losses, while the remaining 46 per cent is rejected in the form of heat to the condenser. To improve the efficiency of the turbine we require to increase its range of temperature, and the only practical way to do so at present is by additional superheating of the steam. The difficulty in using high superheat for turbines is purely one of construction, calling for the use of special materials and improved methods of fixing and arranging the parts exposed to the higher temperatures. Bearing in mind the tremendous advance which has been made in recent years, there is good ground for believing that these difficulties will also be overcome. In the meantime they constitute the chief limitation to a higher efficiency being obtained from the steam turbine.

DIESEL ENGINE.

The high thermal efficiency of the Diesel engine, which may be taken at 30 per cent (or twice the efficiency of the

water-tube-boiler-steam-turbine combination), constitutes a strong claim for its adoption in central-station work. A further advantage is the absence of stand-by losses, and also the ability to bring an engine into use at very short notice. The chief limitation in my opinion to the use of Diesel engines on a large scale for central-station work is our dependence on foreign countries for supplies of oil fuel. It is true that the Navy and also the Mercantile Marine are adopting oil fuel either for raising steam or to burn in the engine cylinder direct, but it must be remembered that for marine purposes the use of oil fuel possesses many important advantages (such as increasing the radius of action in the case of battleships) which are of course absent in the case of central stations. We should be dependent on a price which might fluctuate within wide limits, and if, as appears probable, the use of oil is extended in the Navy and also in the Mercantile Marine, there may be difficulties in meeting the demand. Having regard to these considerations, I am of opinion that British engineers will do wisely to confine themselves for central-station work to a type of plant which can be operated with coal, our natural fuel, of which we have, and are likely to have, an abundant supply for many years to come.

Producer Gas Engines.

The producer gas engine can be operated with almost any kind of coal fuel, and has a thermal efficiency considerably better than the steam turbine, although rather less than the Diesel engine. Its efficiency may be taken at about 27 per cent, or if producer losses are included, there is a combined efficiency of about 24 per cent. Of these losses about 20 per cent will be absorbed in the cooling jacket, and about 30 per cent ejected to the exhaust pipe. If it were possible to increase the range of temperature and construct gas engines of compound or triple expansion type, a much higher efficiency could be obtained, but the mechanical difficulties in the way of making compound gas engines are enormous, and unfortunately these multiply as the size of the engine is increased. The limit at present appears to be single-stage engines of 4,000 horse-power. There is still room for improvement, and I believe the gas engine will play an important part in the central station of the future.

If we could combine the mechanical and operating advantages of the steam turbine with the thermal efficiency of the gas engine, we should have a much improved combination. The efficiency of a gas engine is highest with a steady load, but that type of engine has practically no capacity for overload. The steam turbine, on the other hand, has a high capacity for overload, and is fairly efficient at light loads. If these two types of prime-movers were combined in one generating station, it would be possible also to recover, for the purpose of raising steam in specially constructed boilers, a large proportion of the heat now rejected to the gas-engine exhaust, while the heat absorbed in the cylinder water-jackets could be utilized as feed water for the steam boiler. With a combination of this kind we could, I think, raise our station efficiency from the present figure of 15 per cent to something like 25 per cent. With such an efficiency, and with the further advantages that concentration gives in the way of lower first cost and reduction of standing charges, there is no reason why electricity could not be sold under a scheme such as that outlined by Dr. Ferranti three years ago, at a price which would enable it to be used for every conceivable industrial and domestic purpose.

Assuming that the engineering problems were solved, there is still a serious difficulty in establishing any scheme for the generation and supply of electricity on a lage scale, due to the existing interests which have been established under statutory authority. There are already between 400 and 500 supply undertakings in this country operating under Provisional Orders or special Acts, of which about three-fourths are owned and operated by local authorities.

There has been a tendency in certain quarters of late to decry the backward state of our industry, which is attributed to certain specific causes:—

First, the restrictive legislation imposed by Parliament on private companies; and

Second, that the bulk of electric supply undertakings in this country are in the hands of local authorities.

To prove this contention, statistics are sometimes given showing the relative consumption of electricity in this and in other countries on the basis of units sold per head of population. I cannot quite agree with either of these views. If our alleged backwardness were confined to electrical applications, the argument might have more weight, but as a matter of fact it extends to many other industries which are not in the least affected by legislation. Take the case of our railways. They are owned and managed by private enterprise, no restrictions by Parliament or local authorities exist to prevent them taking up and working new ideas, and yet in the matter of railway electrification, and even in such details as automatic signalling, we are relatively far behind other countries. These comparisons with America overlook the difference in conditions which exists between a country having a much larger area, with a rapidly increasing population, with new districts opening up, and with new industries being constantly introduced, and an older country like Britain densely populated, with many old-established interests, and with a natural conservatism which clings to existing ideas and systems. It must also be remembered that while in America the prices charged for electricity are comparatively high, they are relatively more favourable to electricity than the prices charged in this country, where we have to compete against the cheapest gas in the world.

The charge made against municipalities of obstructing electrical progress is also, I think, somewhat unfair. Nothing can be said on behalf of a municipality which follows a pure policy of obstruction; but cases of that kind are, I believe, the exception rather than the rule. On the other hand, it can safely be said that our municipal electric supply undertakings, especially those in large cities and industrial towns, have shown results which will compare very favourably with the results obtained by private companies. In the case of smaller municipalities it should not be overlooked that many of them embarked in the business of supplying electrical energy at a time when bulk supplies were not available, and they have survived through a period when the conditions were not nearly so favourable as they are to-day. They are all under obligations regarding repayment of capital from which private companies are exempt, and on the whole have shown good financial results with

moderate charges for supply. They have educated the public to the use of electricity and have provided much valuable experience. In the light of our present knowledge it would appear that most of these smaller generating stations will ultimately be superseded by a bulk supply from another authority; but having regard to the conditions under which they were started and have been operated, it is hardly fair now to charge them with obstruction for continuing to operate undertakings which have hitherto met all local requirements. It would also be unfair to permit a power company to enter these areas and pick out the larger power users at competitive prices, leaving the local authority to supply the lighting and small power users only.

We have to face the position that these undertakings are already in operation, and the problem of cheap supply for all purposes will not be solved by purchasing a municipal station here or supplying in bulk elsewhere. The question is too big to be dealt with by isolated arrangement, and while co-operation between the various local authorities themselves and between local authorities and power companies may require to be entered into as a temporary expedient, the ultimate solution must come from a scheme dealt with on broad national lines; such a scheme is at least as important as the telephone service, and would justify the appointment by the Government of a commission of experts to investigate the whole question and report fully with special regard to such problems as suitable generating centres, the economic radius of supply, the standardization of voltages and periodicities, and the purchase of existing interests.

Transmission.

For transmission of energy high-tension multi-phase current has become standard practice, and in view of the adaptability and efficiency of this system for all conditions it is hardly likely to be superseded. The use of multi-phase low-pressure current for power purposes is also on the increase, and in the light of present experience it may be questioned whether central-station engineers in this country have acted wisely in adopting wholesale a 3-wire transmission system which temporarily increased the economical radius of supply but has since proved to be only a stop-gap between the low pressure 2-wire continuous or single-phase current and the present system of high-tension transmission. Reliability of supply and absence of breakdown, either to our mains or to the wiring on consumers' premises, are of primary importance, and from this point of view the simplest and most reliable system is undoubtedly a 2-wire system of distribution with high-tension transmission to sub-stations. The undertaking with which I am associated employs 3-wire distribution, partly from the generating station and partly from sub-stations, but in an extension to a neighbouring town now being carried out we propose to use a 2-wire distribution system throughout for power and lighting. In this case we had to deal with a number of consumers with demands ranging from 200 kw. up to 800 kw., some of them having private installations operated at pressures from 200 to 250 volts. The position of these consumers enabled them to be grouped together on two sub-stations with short lengths of feeders, and on going into the matter I decided to adopt the pressure of 250 volts on a 2-wire system for both kinds of supply. The additional expense involved, compared with a 3-wire system for the same area, is not more than 25 per cent in this particular case, and I am of opinion that the saving effected in balancers and switchgear and the benefit of interchangeability between the power and lighting systems, combined with the simplicity and safety, will fully compensate for the extra cost.

Storage Batteries.

Recent developments in the manufacture and use of storage batteries are claiming considerable attention. When central stations were first built, storage batteries were installed to equalize the load or to maintain the supply during week-ends to enable the steam plant to be shut down. As the stations grew larger they outgrew the capacity of the battery, and in many cases batteries were discarded or retained simply for load-levelling and balancing.

In electric traction systems the battery has been more generally used, and has been of considerable assistance in dealing with rapid fluctuations of load. Quite recently the question of batteries has come into prominence again, and in one large municipal station a battery capable of discharging at 3,000 kw. on a one-hour rating has been installed. This is still a long way behind the sizes of batteries employed in lighting stations in America, where it is not unusual to keep a battery capacity sufficient to take the whole of the station load for short periods. The New York Edison Company have a battery of 11,000 kw.-hour capacity on a one-hour rating, but which is capable of discharging at 25,000 kw. for short periods. The use of such batteries is twofold. They can be employed to deal with sudden demands and also for the daily peak loads, and for this purpose they may be compared with an equal capacity of generating plant. Their more important function, however, is to take up the load automatically in the event of a breakdown of any unit of the generating plant. From this point of view I think a large battery is justified. It is becoming increasingly important to secure reliability of supply, and the annual charges on the battery may be looked on as a form of insurance against breakdown. The security and stability which a battery gives to the station under these conditions are certainly worth paying for. With a multi-phase system of transmission the proper place for storage batteries is of course in the sub-stations, where they can be used as a stand-by, as load-levellers, and also enable the high-tension plant to be closed down at times of light load for testing or repair.

The chief limitation of the storage battery is the use of lead for electrodes and acid for the electrolyte. Much has been done to improve it both mechanically and chemically, but many of the original defects still remain. These are the great weight in proportion to capacity, insufficient mechanical strength, rapid deterioration of electrodes, and inability to withstand heavy charges or discharges without injury. The duration of the lead-plate central-station battery is not more than 7 or 8 years, and to obtain even this life a battery requires very careful attention.

Electric Automobiles.

In America much attention has been given to the storage battery for automobile purposes, and many of the defects of the lead battery appear to have been successfully overcome. The greatest advance is undoubtedly the battery

invented and perfected by Mr. Edison after 8 years' experimenting. In this battery the lead plates are substituted by electrodes of steel and nickel, and an alkaline electrolyte is employed instead of an acid. It is said to combine comparative lightness with great capacity, and mechanical strength is attained without any reduction in efficiency. It can be discharged at almost any rate up to the short-circuiting rate without apparent injury, and although it is advisable to charge at normal rates, it is possible to give the cells short "boosting" charges of half an hour's duration at five times the normal charging rate. The use of an alkaline electrolyte overcomes many minor troubles, such as the corrosion of terminals which is experienced with acid batteries, and the mechanical arrangement of the electrodes and terminals is a great advance on former practice. At present it is somewhat expensive compared with the lead battery, and its use at first will be chiefly for automobile purposes. The makers claim that when used on a taxi-cab service doing an average duty of 50 miles per day the battery will propel the car 150,000 miles—practically a 10 years' life—without requiring renewals or mechanical repairs, and they are prepared to enter into a guarantee that after 4 years' use under all possible conditions of automobile service the car will retain its original capacity. If these claims are substantiated, it appears that we are at the beginning of a new development of automobile work which is bound to have a far-reaching effect on the electrical industry.

We have had practically no experience of electric automobiles in this country beyond one or two half-hearted attempts which were made some years ago to run an electric omnibus and cab service in London. On the other hand, there are in the United States over 20,000 electric automobiles in daily use, and over 40 firms engaged in their manufacture. The capital invested in the industry is £12,000,000, and the energy used for charging is estimated at 65 million units per annum. What opportunity is there for the electric automobile in this country? Compared with the petrol car, the advantages of the electric vehicle are its simplicity of construction, freedom from repair, easy and noiseless running, and better control. With electricity at 1d. per unit the electric vehicle compares under present conditions very favourably for economy with petrol cars. As the batteries can be charged at times convenient for the power station, the load is one which most station engineers would be glad to supply at ¾d. or even ½d. per unit.

The limitation of the electric car is of course its restricted radius of travel on a single charge. Even if charging stations were established over the country this would still constitute a disadvantage to those who desire quick travelling over long distances. There is still an enormous field, however, for the electric car in cities and towns, where its advantages over the petrol car will be specially appreciated.

The commercial car offers still greater possibilities for the use of secondary batteries. In this case the disadvantage of limited radius and moderate speed do not apply. The commercial car as a rule travels from 25 to 35 miles a day, and returns to the same garage at night. Wear and tear of petrol engines on these heavy cars is a considerable item, and it is considered necessary to allow depreciation on the basis of a five years' life. As an instance of what is being done with commercial electric cars, I might state that when in Paris on the occasion of the visit of this Institution last May I took the opportunity to call at the municipal department which is responsible for the collection of the city's refuse and its transmission to the destructors, where I had the privilege of examining and testing some 5-ton electrically-propelled refuse wagons, one or two of which had been in experimental use for nearly two years. The battery, which was of the lead-plate type, specially manufactured for the purpose by a French firm, was contained in boxes in a fore-carriage, and the motors, of which there were two, each rated at $7\frac{1}{2}$ h.p., were mounted under the carriage and geared to the front axle. The equipment was arranged for 4 forward speeds and 1 reverse speed, with electric braking on the regenerative system. These operations were all performed by a single handle connected through gearing to a tramway-type controller. The steel body was divided into five compartments, and coupled to the fore-carriage in such a way that it could be detached by unlocking two screw-bolts, and replaced, when required, by a street-sweeping machine or watering-cart. Anybody who has driven a heavy commercial car of the petrol type could not help being impressed with the superiority of the electric car for this class of traffic, and it was not surprising to learn that the Paris municipality, after making tests extending over two years with both types, had decided to adopt the electric. An order had been placed for 100 wagons, the idea being gradually to replace the whole of the horse-drawn vehicles used by this department. Several other towns on the Continent have decided to adopt the electric car for municipal purposes.

There is undoubtedly a great field in this business awaiting electrical engineers in this country, and if properly introduced and organized it should mean a large addition of trade for manufacturers of batteries and motors, while incidentally providing a desirable load for central stations. It is to be hoped that when this new business is introduced to this country we shall avoid the blunders which we have made with nearly every electrical development up to the present, and go in for a complete system of co-operation and standardization from the beginning. It will be absolutely necessary to standardize the charging voltage of batteries, and the capacity for each particular size and type should also be kept as nearly uniform as possible. There is no reason why the motors and control gear should not also be made in standard sizes, so that replacements of any part could be supplied from stock with the minimum of cost and inconvenience to the users.

To attain success there must be thorough co-operation between the manufacturers and the supply engineers, and the question is one of sufficient importance, I think, to claim the consideration of a committee of this Institution representing the various interests involved. If these interests work together on proper lines there is no reason why the electric automobile business should not be at least as successful here as it has been in the United States.

Heating and Cooking.

Generally speaking, the outlook for the electrical industry was never more hopeful than it is at present. Electric lighting has passed out of the region of controversy, while

the electric motor is fast superseding all other forms of power application. Another branch which has developed rapidly of late is electric heating and cooking. As regards heating, we have now numerous designs and types of radiators and convectors to meet all conditions. The convenience and cleanliness of electric heating constitute its unique advantages, and its limitation at present is purely financial.

With regard to electric cooking the position is still more favourable. Owing to the great efficiency of electric cooking devices as compared with either coal or gas appliances, a sound case can be made out for electric cooking from the point of view of economy, in addition to its other advantages. The only exception at present is the difficulty of furnishing an adequate supply of hot water for all household purposes. In the meantime the best arrangement seems to be a combination of electric cooking with a water heater fired by anthracite or coke. From personal experience I can say that this arrangement is thoroughly satisfactory and economical.

The design and construction of cooking apparatus has advanced enormously during the last two years, but there is still room for improvement. There is a difficulty at present in obtaining a heating element which is cheap, mechanically strong, and which will work continuously in household use for more than 2 or 3 years at a temperature corresponding to red heat. Many firms are now engaged on this problem and I have not the slightest doubt that it will be successfully overcome in the near future. An important point to remember in connection with electric cooking is that of safety in handling the appliances. Electrical cooking appliances in the kitchen should at least be as safe as apparatus in a factory which has to conform to Home Office Regulations.

We occasionally hear criticism of the low prices at which electricity is sold for heating and cooking as compared with the rates charged for lighting. There are sound reasons why electricity can be sold for these purposes at so low a rate as 0·5d. per unit, even in those cases where the cost of production may be substantially greater.

It would be out of place to discuss these reasons here, but I would only point out that it may be perfectly sound policy for a trader to introduce a new article to the market at a price below its actual cost if by so doing he can attract a volume of business sufficient to reduce the cost of production to a figure which will yield a profit and at the same time recoup him for his preliminary losses.

Electricity is an ideal agent for performing the work now carried on by the burning of coal, either for industrial or domestic purposes, and it is at least a debatable proposition whether our local authorities would not be justified, from the public health point of view alone, in selling electricity for domestic purposes even at a loss in view of the tremendous benefits to be obtained by abolishing the smoke cloud over our cities and towns. Dr. Ferranti's remark at the Scottish Local Section dinner two years ago is worth recalling. He said that "the smoke nuisance in our cities would be abolished as soon as the people realize that a pure atmosphere is worth paying for."

DUBLIN LOCAL SECTION: CHAIRMAN'S ADDRESS.

By G. Marshall Harriss, Member.

(Address delivered 14th November, 1913.)

It is customary on an occasion such as this to review the work of the past 12 months and the works in progress and contemplated, and to form some opinion as to the state of our profession generally and its prospects for the future. At the present time I am afraid we are not in that easy condition of mind necessary for the calm consideration of these matters; for we have experienced nearly three months of the effects of labour unrest in this city, and we are still unsettled.

Apart from these troubles, the prospects for our profession are highly satisfactory. It is true there are not many recent undertakings of any considerable magnitude, or of exceptional nature to which to point. This is not because the resources of the electrical engineer are in any way exhausted, or that the limits have been reached in the useful application of electricity; for every year adds further proof of the great flexibility of electricity as a medium for the transmission of power on commercial lines over great distances and for all possible purposes.

No doubt the Board of Trade Regulations prohibiting the use of bare overhead wires carrying high potentials have been largely responsible for keeping back the progress of electricity supply from large central stations over wide and thinly populated areas. These regulations are being steadily relaxed, and municipal undertakings now stand most in the way. Much as we owe the municipal authorities for their early enterprise in the development of electricity for lighting and other purposes, we are now confronted with the fact that they stand in the way of expansion. They themselves are unable to go far afield by reason of the fact that their powers are restricted to limited areas, and their trading instincts prompt them to prevent anyone else from undertaking this work, as instanced by the vigorous and successful opposition to the recent Power Bills. But the great central power stations must come sooner or later, and the sooner the better for the country at large and incidentally for the electrical engineer.

If we have not many recent large works to point to, we have nevertheless been doing good work. Electrical engineers have of late more settled down to the work in hand, and they have been directing their attention more to keeping in order and improving the appliances available than allowing themselves to be carried away by attractive and untried ideas and inventions; and as a result substantial progress has been made in matters of detail, which means progress upon proved lines.

In traction work, especially as regards street railways, or tramways, great progress has been made; not, however, in the mileage of lines added, that being insignificant, but in the ever-increasing number of passengers carried.

According to the last Board of Trade returns there were 220 millions more passengers carried than in the previous year. On the railways there has been a great falling off.

The Municipal Tramways Association, who present much valuable matter in connection with tramway development, devoted most of their attention at their recent Sheffield Convention to the commercial side of the question rather than the engineering side. From that it is not to be assumed, nor is it suggested, that the last word has been said in tramway design; on the contrary, the present time finds all the large undertakings, especially the older ones, busily engaged in their workshops, not merely maintaining and adding to their rolling stock, but re-designing it so as better to meet the increasing demands. The tendency is for larger cars, covered-in tops, and faster running, all of which call for more powerful equipments, while in the light of increasing knowledge defects are being guarded against and improvements introduced, and in this way much sound and useful engineering work is being done.

Where new track is being laid, or old work renewed, the tendency is in the direction of heavier rails and more costly work all round, with the object of making the installation as permanent as possible. In the overhead equipment and its general construction and in the methods of distribution of electrical energy and its control, very few changes have been made or called for in recent years; indeed, in that direction the early engineers did their work well, and perhaps no part of a tramway system has given less trouble or more satisfaction. Phosphor bronze and other alloys exploited by different manufacturers of repute are largely finding favour in the replacement of trolley wires, originally of hard drawn copper. In the matter of "conditions" a most important matter to both tramway undertakings and the public is the recent agreement of the Postmaster-General to use covered wires instead of bare wires in all cases where the Post Office wires cross the tramway overhead lines, so doing away with the necessity for guarding the trolley wire in such places with the cumbersome and dangerous network of steel stranded wires.

In the generating station the increasing cost of coal calls for the engineer's more careful attention every day. Efficiency in every direction is of growing importance, and coal-saving devices, either not before developed, or not before considered worth adopting, have now to be carefully investigated. The reciprocating steam engine is giving way to the steam turbine, but it still has a place and is doing excellent service, particularly when working in conjunction with turbines of the exhaust or mixed-pressure type; indeed, where so arranged and under suitable conditions, results equal to the very best for low coal consumption are being obtained.

Engines of the internal combustion type, notwithstanding their enormous success and extended use for small powers, are now no nearer finding a place in the large power stations than they were some years ago. Steam as a medium for power production still holds the premier place. Development with a view to greater economy points at present in the direction of higher pressure and superheating to a degree far in excess of anything we have heretofore been accustomed to; the consequences in this direction cannot be viewed without apprehension, for the necessity for better material, a higher class of workmanship, more costly maintenance charges, and more careful attention, will increase with the pressure and temperature, while the results of any failure in any of these matters will be magnified. At best the life of the whole of the apparatus must be shortened and the first cost and cost of maintenance and operation increased.

In the boiler house we have still enormous losses going on, and perhaps less has there been done and there is more room for improvements than in any other part of the power station. But in that direction the Bonecourt boiler, which is designed for gas firing, promises almost to revolutionize the methods of steam raising; it opens the door to all fuels, such as peat and sewage sludge, and while an efficiency of 92 per cent is claimed for the boiler, valuable by-products can be recovered from the gas producer.

In electrical machinery the improvements in rotary converters are valuable. Some advancement has been made towards the development of the single-phase motor. If this can be perfected to the same extent as the continuous-current or the polyphase motor it will widen the economical range for power transmission and greatly lessen the difficulties connected with distribution. With cheap fuel, whether at the pit's mouth or in this country at the bog side, and with improvements in boilers or gas engines, and with a satisfactory single-phase alternating-current motor, perhaps we may yet see electricity largely used in the cultivation of the land, thereby becoming the means of solving a great economic difficulty in that direction.

The farmer's margin of profit is so small and the amount of manual labour required in farming is so large that labour can only be poorly paid. The farm labourer's work is unattractive to young men, not on account of the small pay, but because the prospects for advancement are remote. Cheap power in a flexible form would lighten and cheapen the drudgery work, permit of higher pay for labour, and open a field for the exercise of intelligence of a high order; in this way, perhaps, electricity may eventually do more to bring the people back to the land than any legislation that can be devised.

I should like to say a few words on the subject of accounts and records. It might at first sight appear that there was no necessity for any more figures, on the grounds that those available are sufficient to enable us to analyse the different undertakings in every way that is of practical value. In the main I agree with this, but in one very important direction I venture to suggest we are working very much in the dark; I refer to the money we are spending on the upkeep of machinery, and the absence of records to enable us better to judge of the value we are getting for the expenditure.

It is a matter for judgment, backed by experience, as to what is the best way to spend money on each piece of machinery to keep it working efficiently. We usually class money spent in this way in part or entirely under any of the heads "maintenance," "repairs," and "renewals." These terms explain themselves, but the difference between them is not generally understood.

The object I have in view is to suggest a simple way of keeping records, which will show in each case what was in the mind of the man directing this expenditure and so provide a means for testing his judgment, incidentally enabling us to ascertain the value of each particular machine at any

time, as affected by the work it has done, and the money that has been spent on keeping it in order. It follows that if we can get so far, we shall also have a means for finding from our records when the useful life of any machine is approaching its end, or when it has reached the end of its economical life.

The system I propose involves the opening of an account for each separate unit or piece of machinery, and in these accounts the money spent on that unit is assessed as follows:—

Under "Maintenance" put the cost of any minor parts that regularly wear out more rapidly than the whole, being common more or less to all machines of the same kind, such as re-lining bearings with white metal, new brushes for a motor or generator, etc.

Under "Renewals" charge any part that is put in complete and which leaves the unit as a whole (making allowance for wear and tear) in the condition it would be when the whole was new; that is to say, the unit must be at least as good, if not better, after the new part has been added, as in the ordinary way it would be had the new part not been necessary. There is no limit in size or cost as to what may be properly considered a renewal. A new set-screw might be so assessed if the addition did not involve serious cutting away of metal in re-tapping to receive it, or doing anything else calculated to weaken some other part; but if when it is put in it is liable to want changing again before the whole wears out, it then cannot be charged as a renewal.

It is not necessary that a renewal should be always made with an absolutely new part. For instance, a machine may be in such a condition that taken as a whole the installation of a complete new major part would not be justified. In such a case, if there be available a part that had been taken from another machine and its installation will make the whole uniform as regards life, then this cost may be assessed as a renewal. Credit would also be allowed for a part taken out of a machine when that part either has a scrap value or is available for use again after repair.

Under "Repairs" must be put everything that is done other than "maintenance" or "renewals." A unit as a whole is always somewhat worse for everything that is done to it which cannot be properly charged under the other two heads. For instance, if any of the journals get scored and have to be turned up, that is a repair. Rewinding part of an armature or field-coils, turning up commutators, and such matters, are repairs. If any part is fractured and is mended in any way, this brings down the value of the whole, and on that ground is a repair. When a part that has been repaired is renewed, the cost of such repair no longer stands against the unit, and it is left out of consideration in arriving at its value. In the accounts kept in the above form a very accurate analysis of the expenditure would exist. They would contain a record as to the amount of money spent on each unit and the direction in which it went.

A ready means for arriving at the actual value at any time would be provided by deducting the depreciation from the original cost and adding the scrap value, depreciation being arrived at in the following way:—

$$\text{Depreciation} = \frac{\text{Original cost of machine} \times \text{Time working}}{\text{Lifetime}} + \begin{array}{c}\text{Depreciation due to the nature}\\ \text{of the repairs standing.}\end{array}$$

The original cost and the length of time in use are figures which are available. The life-time, if not settled, would be arrived at in whatever way experience showed to be the best.

As to the Institution, I do not know what are the actual results of the recent changes in our constitution as regards making test examinations compulsory before admission, and the creation of the "Graduate" class. No doubt this latter has already brought in, and will continue to bring in, many desirable men who otherwise would not have been reached. I do not think there is any room for question as to the soundness of the principle aimed at. This is only a means to an end, the end being to raise the status of our profession.

We have followed the lead of the Institution of Civil Engineers in introducing entrance examinations, which was advocated by this Section in 1911. This is good, but we should go further. The solicitor's clerk is not a solicitor, the apothecary's assistant is not an apothecary, the apothecary is not a doctor, the sexton is not in Holy Orders, and the mechanic who makes up false sets of teeth is not a dentist. They cannot call themselves such, they cannot act as such by law; but the plumber, the wireman, the engine driver, the commercial agent of a manufacturer, are all "engineers," and can and do act as engineers, and can and do recover fees as such, independent of qualifications.

How can this be mended?

If there were no precedent it might seem hopeless to evolve order and create a profession out of the present chaos. Fortunately we have in the Medical Act of 1858—barely 50 years ago—an example of how the thing not only can be but has been done. In that year the medical profession was in much the same state as the engineering profession is now—with no standard of qualification and no legal rights. In that act no injustice was done to anyone than earning his living as a bona fide medical practitioner; and if we follow suit, any Act sought by us must fulfil the same condition.

By the courtesy of the Dublin Medical Registrar I have obtained a copy of the medical register from which I get the following information.

On 2nd August, 1858, an Act of Parliament was obtained for the medical practitioners, so "that persons requiring medical aid should be enabled to distinguish qualified from unqualified practitioners," the object of which was to raise the status of the profession of medicine and surgery by making it illegal for anyone to practise unless registered as the possessor of bona fide qualifications. The Act after providing for the formation of a medical council and branches and the appointment of a registrar enacts (Section 15) that every person then possessed of certain qualifications described in the Schedule (A) should upon payment of a fee be entitled to registration.

Section 18 provides that any person who was actually practising medicine in England before 1st August, 1815, or some 33 years before the passing of the Act, was entitled to registration upon making a declaration to that effect. While the Schedule A referred to provided for the taking in of everybody who had any reasonable qualifications for recognition.

Section 31 gives power to every registered person to

practise medicine or surgery or both, as the case may be, according to his qualifications, and confers certain rights as to the recovery of fees by law, but legalizes such by-laws as may be made by any College of Physicians preventing its Fellows or Members from suing for fees.

The next section provides that only registered persons can recover fees by law.

Section 36 sets out the appointments that an unregistered person cannot hold. These include every public appointment that is of standing, such as physician or medical officer to the Military or the Navy or any Public Institution, Friendly Society, etc., while Section 37 enacts that no medical certificates will be valid unless signed by a person registered.

Section 40 enacts that any person who shall wilfully and falsely represent himself as registered when he is not shall upon conviction pay a sum not exceeding £20.

Section 46 provides for persons practising abroad.

This early Act was amended twice in 1858, once in 1862, once in 1868–73, twice in 1875, and once in 1876–83, and it was repealed three years later. The last amendment Act is, I think, that of 1905, giving power to extend portions of the Medical Act of 1886 to the Colonies.

None of the subsequent Acts departed from the original purpose of the Medical Act of 1858; on the contrary, except that the powers were made to reach further, and ladies were allowed to qualify for registration (the Medical Act Royal College of Surgeons of England, 1875), the subsequent Acts strengthened and further raised the status of the medical practitioner.

The Perjury Act of 1911 (1 & 2 Geo. 5, Cap. VI.). Sections 6, 7, and 17, gives power to punish persons, aiders, or abettors, etc., for making false declarations, by imprisonment or fine or both in respect to attempts to procure false registration.

Before the year 1888 the dentists, like the early physicians, seeing that their profession was being encroached upon by unqualified persons and that those qualified were without any protection or distinction, got together, and as a result an "Act to amend the law relating to dental practitioners" was passed in that year.

This Act is not so useful to the dentists as the Medical Act of 1858 is to the doctors. It is, I understand, shortly to be amended, but to do this successfully now and secure a useful instrument, no injury must be done to those already established.

The way to raise the status of the engineer is to make the profession recognized by law. The way to do this has been shown us.

THE BRITISH STANDARD SPECIFICATION FOR CONSUMERS' ELECTRIC SUPPLY METERS.

By S. H. Holden, Member.

(*Paper received 15th September, and read before the* Birmingham Local Section *12th November*, 1913.)

The British Standard Specification No. 37 was published in 1907. In the opinion of the author this Specification has not so far taken the position in relation to the electricity meter industry which it is desirable that it should do; and he proposes to make certain suggestions which it is hoped will tend to the greater usefulness of the above specification.

There are three sections of the community who are interested in this matter: the manufacturers, the electric supply authorities, and the consumers. Manufacturers have much to gain by a general adoption of a standard specification among their customers, and having arrived by experiment and competition at a satisfactory design which complies with certain definite conditions, they would be saved the inconvenience of constant alteration of their manufacturing processes consequent upon the present system of individual specifications. There will probably always be a certain number of people who will insist on drawing up their own specification, but extension of the Standard Specification would abolish the necessity for this in many cases. The preparation of specifications for electricity meters is quite special work, and it is curious to notice how frequently engineers of ability are betrayed into ridiculous mistakes when they attempt to draw up such a specification.

A further advantage of the general adóption of the Standard Specification is that foreign and colonial purchasers buying either direct or through merchants at home would know that if a meter complied with the Specification it was the best obtainable, and on that account standard English-made meters should enjoy a readier sale and command better prices than those supplied by competing manufacturers.

If consulting engineers and large purchasers were to adopt the same Specification they would save themselves much unnecessary work, and they would avoid the mistakes consequent upon specifying goods when they have not sufficient experience or knowledge of the real requirements. They would also incidentally help to keep down the cost of meters to their clients by avoiding a multiplicity of patterns.

It is essential that a standard specification should be thoroughly up-to-date; this necessarily involves fairly frequent revision. It should also cover all points relating to electricity meters which ought to be specified in the interest either of the manufacturers, the purchasers, or the

consumers; and it should be sufficiently rigorous to exclude all but the best articles. There may be many purposes for which a cheap and inferior meter is useful, but there should be a clear understanding that such meters do not comply with the British Standard Specification.

In the original Standard Specification no attempt was made to differentiate between alternating and continuous-current meters. It is desirable, however, to do so, as it is possible to obtain greater range and accuracy with an alternating-current meter having a pressure coil than with a continuous-current ampere-hour meter; and the best obtainable performance should be specified for each class of meter.

The following alterations and additions to some of the clauses, with one or two new clauses, are now offered for consideration and discussion. Where necessary the clauses have been printed for reference.

Clause 2. "The following capacities, in amperes, shall be recognized as Standard: 3, 5, 10, 25, 50, 75, 100."

The 2½-ampere size is preferable to the 3-ampere size for single-phase meters. The list of sizes should be increased by adding 150, 200, 250, 300, 400, and 500, ampere. The 75-ampere size does not appear to be really necessary.

Clause 3. "The meter shall be contained in a substantial dust-tight metal case of sufficient strength. . . ."

After the word metal case it is proposed to insert the words "of cast iron or pressed steel." Cases of soft metal or sheet jointed together are not used on the highest class of meters.

Clause 6. This clause deals with the terminal box, but only specifies the size of the pressure-circuit terminal. It is therefore proposed to add "The main terminals shall each have two clamping screws. The depth of the hole into which the cable is inserted shall be at least twice its diameter. The following shall be the diameters of the holes for the cables: 10-ampere, 0·22 in.; 25-ampere, 0·32 in.; 50-ampere, 0·375 in.; 100-ampere, 0·435 in.; 150-ampere, 0·5 in.; 200-ampere, 0·6 in.; 250-ampere, 0·7 in.; 300-ampere, 0·8 in.; 400-ampere, 0·9 in.; 500-ampere, 1 inch.

Clause 10. "The meter shall have a suitable place and means upon the front of the case adapted to receive and secure a label to be provided and fixed by the purchaser or his representative. The purchaser's label shall be a rectangular sheet two inches long, half an inch wide, and not more than one thirty-second of an inch thick."

To this should be added: "It shall be affixed by two rivets, and the manufacturer shall provide two holes ⅛ in. diameter and 1¾ in. apart in a suitable position for this label." It is doubtful, however, whether the size specified for the purchaser's label is large enough.

Clause 11. "The dial plate shall indicate the total consumption directly in units, either by means of a number of index hands each travelling round a circular dial on which divisions are marked and figured to indicate units, tens of units, etc., or by means of counter wheels on which digits are marked to indicate units, tens of units, etc., provided that only one digit on each counter wheel shall be visible at a time."

The addition suggested to this is: "If the latter is adopted, the figures on all the wheels shall spring suddenly into position with the exception of those denoting units, which may move at a uniform speed." A counter which can allow of any doubt as to which of two figures is to be read on the higher multiples is inadmissible.

Clause 12. "The fastest-moving index hand or counter wheel shall indicate one unit per division or per digit, and the dial plate shall bear a statement to that effect. A convenient testing index shall be provided in addition, which shall be quite distinct in appearance from the dial proper."

The expression "kilowatt-hour" would be better than "unit," and the number of testing dials should be specified. It is therefore proposed to add: "Meters having a capacity of 2 kilowatt-hours per hour and under to have two testing dials reading 1/10 and 1/100 kilowatt-hour per division respectively. Meters above this capacity and up to 200-kilowatt-hours per hour to have one testing dial reading 1/10 kilowatt-hour per division.

Clause 16. "The main circuit of the meter shall be so constructed that the total loss of power at full load as measured at the main terminals shall not exceed 15 watts subject to the further restriction that the loss of pressure in the main circuit at full load shall not exceed 2 volts in any meter."

As this specification does not apply to electrolytic meters, the 2-volt limit is far too high; ¾-volt is ample. Most engineers prefer to be furnished with definite figures for each size of meter for the fall of potential at full load; the following schedule is therefore suggested:—

2½ or 3-ampere size... ...	... 0·75 volt
5 " "	... 0·50 "
10 " "	... 0·40 "
25 " "	... 0·30 "
50 " "	... 0·20 "
100 " "	... 0·10 "
150-ampere size and upwards	0·075 "

It does not seem necessary to specify exactly any figures below 0·075 volt.

Clause 17. "The pressure circuit, if any, of the meter shall be so constructed that the total power spent in it shall not exceed 4 watts for each hundred volts of pressure. The pressure circuit shall be connected to the supply side of the main circuit and a disconnecting device shall be provided in the terminal compartment to enable the pressure circuit to be entirely disconnected from the main circuit in order that it may be supplied with current from a separate source when necessary for purposes of testing."

The consumption of energy allowed by this clause appears to be far too high. The consumption in the pressure circuit of single-phase meters should not exceed 2 watts, and for continuous-current meters 7 watts, at the declared pressure, provided this does not exceed 650 volts.

Clause 19. This deals with starting currents. A first-class single-phase meter should start with ½ per cent of its full-load current at a power factor of unity. A continuous-current ampere-hour meter should start with 0·05 ampere if of 10-ampere capacity or under, and with ½ per cent of full load if over 10-ampere capacity.

Clause 20. "The error of a meter when tested at the marked temperature, pressure, frequency, and unit power

factor shall not exceed two-and-a-half per cent at any part of the range from full load down to one-tenth of full load. At any part of the range below one-tenth of full load down to and including one-twentieth of full load the percentage error shall not exceed the figure which is obtained by dividing, by four, the denominator of the fraction expressing the proportion the load bears to the full load, that is to say, at $\frac{1}{N}$th of full load the error shall not exceed $\frac{N}{4}$ per cent."

This stipulation appears to be insufficiently rigorous and too clumsy for ordinary use. Alternating-current meters can easily be made within 2 per cent from one-twentieth full load to full load; and the same applies to continuous-current ampere-hour meters except that the lower limit should not be less than half an ampere. No guarantee of accuracy above or below these limits should be asked for or given.

Clause 25. "When a meter has a pressure circuit a variation of 10 per cent above or below the marked pressure shall not cause an error in respect of such variation of more than 1 per cent."

Clause 26. "When a meter is intended for use on an alternating-current circuit a variation of 5 per cent above or below the normal frequency shall not cause an error in respect of such variation of more than 1 per cent."

Clause 27. "When a meter is intended for use on an alternating-current circuit a variation in the power factor of the load from unity down to one-half shall not cause an error in respect of such variation of more than 2 per cent."

Clauses 25, 26, 27, all appear to lack definiteness, as the author has found that different interpretations are put upon them. The most usual interpretation leads to the absurdity that if, say, a meter is 2 per cent slow at normal voltage and a 10 per cent rise of pressure makes it correct, it must be rejected because the rise of pressure has caused more than 1 per cent variation, while if the same rise of pressure makes it 1 per cent slower (that is 3 per cent total error) it will be accepted. It is suggested that the words "shall not cause an error" be altered to "shall not increase an error."

Variation of Wave-form.—This is not dealt with in the Standard Specification, but it is not unusual for consulting engineers to specify that meters shall be unaffected by variations of wave-form. The author, however, never came across a specification in which variations of wave-form were defined or limited. As a matter of fact alternating-current meters should not be affected by such variations in wave-form as are usually met with in practice. For the sake of completeness it is suggested that a clause be inserted to the effect that a variation of wave-form of 10 per cent from a true sine curve at any point shall not increase the error of the meter by more than 1 per cent.

It may be pointed out that slight additions to the Specification would make it cover polyphase meters; and in view of the large number of such meters in use their inclusion is very desirable.

At the conclusion of the Specification there is a note to the effect that an appendix, which would apparently deal with some of the points raised in this paper, was in preparation; so far, however, it has not been published.

In conclusion, the author suggests that the Institution should urge the Engineering Standards Committee to publish, as soon as possible, a revised and completed Specification for electricity meters, and that with a view to its wider use and circulation the price should be reduced to one shilling per copy in order that manufacturers may be able to include copies with their tenders. Those purchasing or specifying meters should also be urged to make use of the full Specification, without additions as far as possible, especially when meters are purchased for export. And some distinguishing mark should be placed upon meters which are sold as complying with the British Standard Specification.

A TWO-RATE TARIFF SYSTEM WITHOUT TIME-OPERATED CONTROL.

By H. H. PERRY, Member.

(*Paper first received 9th September, and in final form 28th October; read before the* MANCHESTER LOCAL SECTION *18th November*, 1913.)

It is only within the last few years that electric heating and cooking have been energetically brought to the knowledge of the consumer by supply authorities. The reason for the tardy introduction no doubt lay in the untrustworthiness and poor efficiency of some of the apparatus. Vigorous efforts by manufacturers, however, have now opened up an entirely new field.

In Mr. T. P. Wilmshurst's paper * it was shown that there were three different periods at which a peak occurred for heating, and the chart areas of those peaks on the load curve were not appreciably dissimilar. One of the peaks coincided with the lighting peak.

A similar and perhaps more striking instance is afforded in the case of Luton, where the claims of electric heating and cooking are afforded full scope. For the past year the output has risen from 2,979,000 to 4,542,000 units, a 52 per cent increase, and the load factor from 19·7 to 20·9, *i.e.* a 6 per cent increase, under the "Point Five" tariff. As in the case of Derby, three heating peaks occur each day, the highest being at mid-day, while the Sunday load is a valuable one.

If, therefore, the average diversity factor is such that the heating peak-loads can be ignored, the problem still remains of basing the high-rate charges on the lighting only. It seems ridiculous to charge at certain times of the day a low rate for power and another rate for lighting for the dual supply, and further, it is equally absurd to exact the full penalty price from a consumer when he is using only a fraction of his maximum lighting load, assuming for the moment that no heating is in use.

In none of the papers which have been read before the Institution in recent years on the subject of tariffs is any suggestion made that the price charged for domestic lighting should, at any period of the day, approach or equal that charged for power except during restricted hours.

The object of this paper is to show :—

1. That the use of electricity can be extended, with advantage both to supplier and consumer, by granting facilities to the latter for using his lighting circuits during "off-peak" hours at a low-rate charge ; and
2. That the multiplication of domestic power circuits, while being an advantage, is not always necessary for securing a low-rate charge.

A simple change-over switch, automatically rocked, can combine or separate the two rates at will. Such a method needs two meters and therefore resolves itself into a

TWO-RATE SYSTEM.

Up to the present, 2-rate clock or centrally controlled systems have not made great headway for the following reasons :—

1. The high cost of meters (clock controlled).
2. Expert workmen are required for clock repairs.
3. Monthly winding.
4. Prolonged period of testing.

And in the case of central control by a system of mains :—

5. High initial outlay.
6. Cable faults.

There is another form of 2-rate meter with two sets of train wheels alternately geared to a single meter and controlled by a series solenoid energized by the lighting-circuit current. This was patented as far back as 1898, and made by the British Thomson-Houston Company, but I understand that its manufacture has been discontinued. It is obvious that such conditions can only apply to motor meters.

In all the above methods of operation, it is not possible to register on both rates simultaneously.

But why go to the expense of any of the above systems in order to change a consumer's meter over from the high rate to the low rate when a magnetic change-over switch will automatically do this ?

DESCRIPTION OF SWITCH.

As shown in Fig. 1, an ordinary single-pole change-over switch is employed, one arm of which is magnetically attracted by the lighting-circuit magnetizing current. It is freely pivoted about its centre, and a balance weight is provided on the other arm, the position of which is adjusted to give any proportion of the consumer's lighting between, say, 5 per cent and 25 per cent at the low rate. In isolated cases it may be practicable to give a higher percentage.

Auxiliary contacts are provided for maintaining continuity of the circuit when changing over ; without these, the practical everyday working of the switch would be impossible. No mercury cups are used.

Demagnetizing turns on the magnet, or a separate counter-magnet, are provided for the purposes to be described in connection with Fig. 4.

The switch is normally on the low-rate side, and two of the ordinary stock pattern of meters are employed, a practice which is daily becoming more common for domestic circuits owing to the demand for power.

Figure 2.—These connections would be used for a consumer taking practically all his current for lighting, no separate circuit being provided.

All the current passes through the high-rate meter

* *Journal I.E.E.*, vol. 51, p. 180, 1913.

(H.R.M.) or the low-rate meter (L.R.M.), and the switch is adjusted by the balance weight or by the air-gap so that all currents less than a given fraction of the maximum current (5–25 per cent) are registered on the low-rate meter.

Figure 3.—A separate power circuit is used, connected to the switch as shown, and two meters are therefore necessary under ordinary tariff conditions. The low-rate meter (L.R.M.) will therefore register the whole of the power load, and up to 25 per cent of that required by the lighting, when the switch is on the low (or left-hand) side. extent. Otherwise the operation is the same as in Fig. 3; that is to say, the lighting reverts to H.R.M. after 5–25 per cent has been exceeded.

To provide equal and opposite magnetizing ampere-turns with equal current flowing in each circuit would court financial ruin if the heating system were maintained over the lighting peak; it is probable, therefore, that the opposing forces would generally be designed so as not to have a greater ratio than 1 : 2, or even as low as 1 : 4, until heating apparatus reaches a very much higher point of efficiency and commands a ready sale to every consumer.

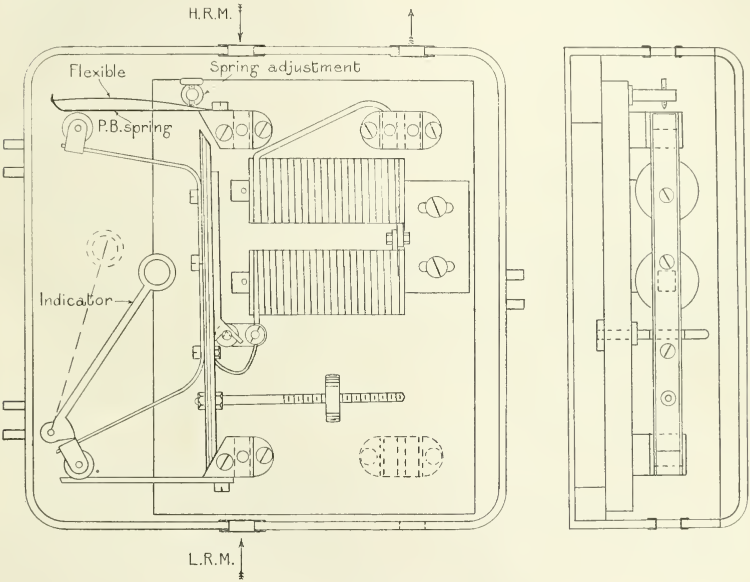

Fig. 1.—Two-rate Switch.

When the switch is on the high (or right-hand) side, L.R.M. will meter the power only, and H.R.M. only the lighting. Both in this case and in Fig. 4 the meters are required to operate simultaneously.

Figure 4.—The consumer has the option of these connections provided certain heating apparatus, such as a complete cooker, a system of radiators, or other power, is adopted, whether purchased outright or hired.

So long as the heater system is in use, L.R.M. will meter all power and any desired proportion of the lighting, since the pull of the magnet is neutralized to the required

Provided always that the heating peak, assuming that there is one only, does not coincide with the lighting peak in magnitude and length of time, the arrangement of Fig. 4 should undoubtedly prove acceptable. The mere granting of a low flat rate for power by many authorities to-day is an admission that the diversity factor is large enough to allow the coincidence of double peaks to be ignored. It has the immense advantage of giving to the consumer the facilities for using dozens of forms of really useful appliances (together with light) from the existing lighting circuits at a low rate, and the load so provided should do

much to improve the load factor, especially during the two summer quarters.

In a 2-rate system it may be urged that the cost of two meters is excessive, especially for the small consumer, who does not, and is unlikely to, use any power, and is therefore connected as in Fig. 2. The answer to that point is that if such a consumer can (by the setting of the auto-

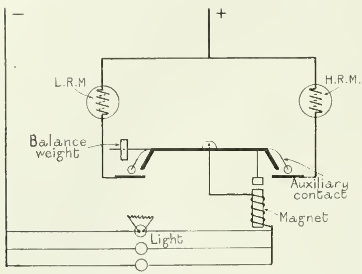

Fig. 2.

switch) save say 10 per cent on an annual bill of £5, he would agree to pay a small additional rental for a second meter. (See also "Appendix.")

If a consumer is connected as in Figs. 3 or 4, two meters are already necessary, and no additional expense is incurred.

There is nothing in this system to prevent the retain-

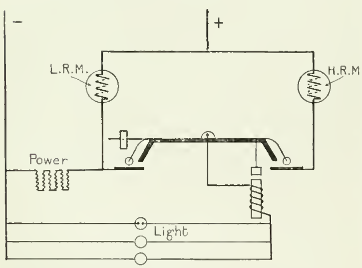

Fig. 3.

ment, or imposition, of a primary charge on the tariff, and it has been suggested that the cost of the auto-switch (about 17s. 6d. for the 10-ampere size) should easily be borne by the consumer in rental, or the tariff made to include it. There are many cases of "necessitated" lights, *i.e.* those which are the first to be switched on and the last to be switched off, and which ought to be distinguished from occasional lights. As already pointed out, it seems misleading to charge a consumer an apparent high rate on these; I say "apparent" because he has little chance of ascertaining his real rate for these on the maximum-demand or primary-charge systems.

To give an instance. It is highly probable that a number of consumers would burn one or more lights throughout the night as a protection against burglary, provided that the cost were small and readily checked.

If heating by electricity is to be made familiar and profitable, it is a *sine qua non* that a hiring department be inaugurated from the commencement—not only from an introductory point of view, but as an educative agency always at the service of the consumer. It is well known to engineers that a watchful eye is generally needed for undersized plug circuits when heating appliances are in use.

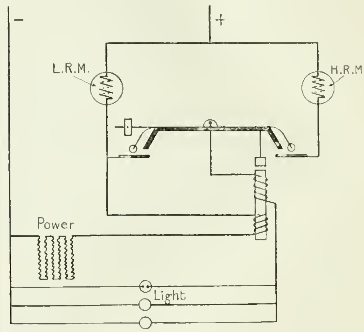

Fig. 4.

Before concluding, it may be useful to revert to a few points in connection with the instrument device, the working of which I have already explained.

1. The well-known effect of residual magnetism has prevented many devices in which instantaneous action is required for a small change in the current from being placed on the market. In the present case a much larger electromagnet than is ordinarily required is provided, and the air-gap is increased with but negligible magnetizing loss. The armature will rock to and fro with a change of only 0·3 ampere for a 10-ampere instrument.

The magnetizing loss at full load is approximately 4 watts with continuous current and 8–10 watts with alternating current.

2. The auxiliary contacts never have to carry more than 25 per cent of the lighting load, except when the arrangement of connections shown in Fig. 2 is employed and a large power load is carried, which is most unlikely. Both contacts are, however, designed to carry full load, so that continuity is assured; the top one only is provided with a flexible phosphor-bronze spring, which tends to give the consumer the benefit by resisting the connection with the high-rate meter.

3. Both auxiliary contacts are fitted with rollers, which relieve friction and tend to revolve with each rock-over motion. They are so pivoted that the break in the circuit as the position of equilibrium is approached is as short as possible. The inductive spark due to the magnetizing current is then negligible.

4. A simple indicator, governed by the magnetizing current, shows the rate in use. The balance weight can, if required, be sealed against fraudulent adjustment.

5. The complete switch in a sealed case measures 7 in. × 7 in. × 2½ in.

Whatever novelty may be claimed for this system I consider that it has at least the advantages of simplicity in working and a clear indication of the charges to be met by the consumer; the latter advantage I feel certain will be readily appreciated by him.

The reduction offered to consumers, whether taking power or not, is an inducement somewhat similar to that inaugurated by gas undertakings, and the increased business resulting would do much to reduce the standing charges.

Appendix.

Figs. 5, 6, and 7 show the methods of using one meter only for a 2-rate system and are intended only for 3-ampere or 5-ampere capacities, with reasonable accuracy obtain-

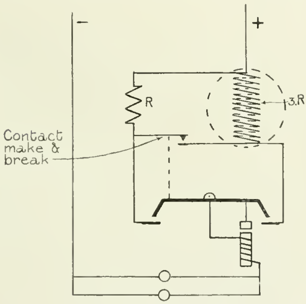

Fig. 5.—Ampere-hour Meter.

able at low powers. It is assumed that the average price charged will be 4d. per unit on the high rate, and 1d. per unit on the low rate.

Ampere-hour type.—The characteristic and resistance of the meter having been ascertained, the value of the shunt will approximate to the value R very closely if

3 R = resistance of meter + external resistance (if any).

In the case of a 5-ampere E.A.C. meter, the following result was obtained with 16-watt and 25-watt lamps :—

16 watts :	1 rev. in	45	secs.	low rate.
	4 „	40	„	high rate.
25 watts :	1 „	21·5	„	low rate.
	4 „	22·5	„	high rate.

The make-and-break contact for the shunted current is actuated by the auto-switch, and the usual stock size

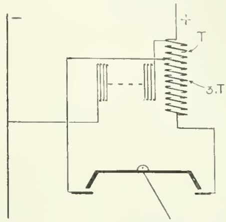

Fig. 6.—Continuous-current Watt-hour Meter.

of meter can be used without internal alteration for 2-rate use.

Continuous-current watt-hour type.—The field coils carrying the main current will be tapped in the ratio of 3 to 1,

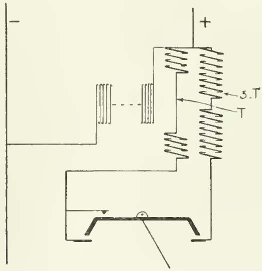

Fig. 7.—Alternating-current Watt-hour Meter.

so that the measurement on the high-rate side will be 3 + 1 = 4.

This type of meter for small consumers is not generally used.

Alternating-current watt-hour type.—The field coils are split into two parallel circuits in the ratio of ⅓ or ¼ to 1 according to the characteristic. The make-and-break contact is employed as in the ampere-hour type.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF THE 13TH NOVEMBER, 1913.

Proceedings of the 556th Ordinary Meeting of the Institution of Electrical Engineers, held on Thursday, 13th November, 1913—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Annual General Meeting held on the 30th May, 1913, were taken as read, and confirmed.

The PRESIDENT : Before proceeding to the business of the evening I have to refer to a matter with which many of you are already acquainted, namely, the great loss that the Institution, the electrical industry, and Telegraphy and Telephony especially, have sustained in the death of our Past-President, Sir William Preece. Sir William Preece was elected to this Institution in the year of its inception, 1871. He served as a Member of Council from 1873 to 1876, as a Vice-President from 1877 to 1879, and as President in 1880, and again in 1893. All who had the pleasure of knowing him appreciated his genial and kindly manner, and more especially his kindness to the younger members of this Institution. We have received a cablegram from the American Institute of Electrical Engineers expressing their regret at our loss and their loss, for Sir William was an Honorary Member of their Institute, and we have replied thanking them for their kind message of sympathy. I now ask you to pass a vote of condolence to his family, by all standing in silence.

The resolution was duly passed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

Donations to the *Library* were announced as having been received since the last meeting from W. T. Anderson, Messrs. Babcock & Wilcox, C. A. Baker, F. Broadbent, The Canadian Department of Mines, Messrs. J. & A. Churchill, W. C. Clinton, A. G. Collis, Messrs. Constable & Co., A. Danvers, The Director-General of Posts and Telegraphs (India), The Electro-Technical Laboratory (Tokyo), The Engineering Standards Committee, A. P. M. Fleming, Professor J. A. Fleming, E. Garcke, Sir John Gavey, C.B., J. X. Gosselin, W. Hibbert, E. G. Hillier, H. M. Hobart, The Institution of Civil Engineers, D. Jaroslaw, E. Kohl, P. Laubach, Marconi's Wireless Telegraph Company, W. P. Maycock, The Meteorological Committee, W. H. Molesworth, Major W. A. J. O'Meara, C.M.G., Messrs. S. Rentell & Co., The Royal Society, A. E. Salazar, A. H. Seabrook, Messrs. Siemens Brothers Dynamo Works, Società delle Forze Idrauliche del Moncenisio, The U.S.A. Department of Commerce, L. H. Walter, W. H. Watkinson, B. Welbourn, and O. J. Williams ; to the *Museum* from R. K. Gray, Mrs. A. F. Grimley, K. Hedges, P. Huddleston, Mrs. Jenkins, Major W. A. J. O'Meara, C.M.G., G. R. Tayler, Major W. F. Cooke Tayler, and C. E. J. Twisaday ; to the *Building Fund* from G. M. Robertson ; and to the *Benevolent Fund* from The Committee for the Protection of Electrical Interests, The Electrical Engineers' Ball Committee, The "25" Club, R. M. Sayers, A. D. Stevens, and W. C. P. Tapper, to whom the thanks of the meeting were duly accorded.

The PRESIDENT : It will be remembered that in 1911 a number of past and present members of the Council formed a Guarantee Fund amounting to over £7,500 to meet any contingency which might arise at any time before the 31st December, 1915. The Council are of opinion that the financial condition of the Institution is now such that the Guarantee Fund is no longer needed, and I therefore move the following resolution :—"That the subscribers to the New Guarantee Fund (1911) be released from their guarantees."

Mr. J. SHEPHERD : I beg to second that resolution.

The resolution having been put, and carried unanimously, was declared by the President to be carried.

The Scholarships and Premiums referred to in the Annual Report* of the Council for the year 1912–13 were presented, and the President then delivered his Inaugural Address on "Pressure Rises" (see p. 1).

Mr. ALEXANDER SIEMENS : After the very hearty applause with which the Presidential Address has been greeted, it is hardly necessary for me to emphasize how very grateful the Institution should be to Mr. Duddell for giving us, instead of a Presidential Address dealing with what may happen in the future, an

* *Journal I.E.E.*, vol. 51, p. 366, 1913.

Address like that of Professor Hughes, when he showed us a microphone, the foundation of the telephone of to-day. I am quite certain that the eloquence with which Mr. Duddell has described his experiments, and the beautiful order in which he has shown his apparatus, which did not fail once during his Address, have made a deep impression upon us, especially upon those who have had to make experiments themselves. I have much pleasure in moving: "That the best thanks of the Institution be accorded to Mr. Duddell for his interesting and instructive Presidential Address, and that with his permission the Address be printed in the *Journal* of the Institution."

Dr. S. Z. de Ferranti : I am sure that all of us who have listened this evening to the President's Address have had the greatest possible treat that anyone could have who belongs to this Institution. To me the Address has been most delightful, and we are accustomed to judge the feelings of others by our own feelings. I think our President should be a very happy man to-night, because I know of no greater pleasure than that of being able to give considerable pleasure to a number of people. I beg to second the resolution.

The resolution was carried by acclamation.

After the President had briefly replied to the vote of thanks, the meeting adjourned at 9.48 p.m.

INSTITUTION ANNOUNCEMENTS.

Papers.

Papers (complete with all tables and illustrations) should reach the Secretary not later than the 31st July if the Authors desire that they should be considered with a view to their being read, if selected, in the first half of the Session (November, December, and January), and not later than the 31st October for the second half of the Session (February, March, and April).

The Papers Committee will also be pleased to consider at any time Papers for publication in the *Journal*.

Annual Dinner.

The Annual Dinner of the Institution will be held at the Hotel Cecil, Strand, London, on Thursday, 5th February, 1914.

Wiring Rules.

The Wiring Rules Committee will be glad to receive suggestions (in the form of specific amendments) as to suitable points for consideration at the next revision of the Rules.

The membership of the Committee includes electricity supply engineers, consulting engineers, manufacturers, and contractors, together with representatives of the Fire Offices, The British Electrical and Allied Manufacturers' Association, The Cable Makers' Association, The Electrical Contractors' Association of Scotland, The Incorporated Municipal Electrical Association, and The Electrical Contractors' Association.

Research Work.

Arrangements are being made by the Research Committee for the investigation of the following matters :—

MAGNET STEELS.

1. What is the relation between the percentage content of tungsten and the coercive force in tungsten steels, preferably in some one series containing a standard percentage, say 0·5 per cent, of carbon, all specimens in the series being quenched at one of the following temperatures, say 700° C., 750°, 800°, 850°, 900°?
2. Whether the presence in tungsten steel of manganese or of silicon is detrimental to either the remanence or the coercive force?
3. What are the magnetic properties of vanadium steel when the percentage of vanadium is varied while the carbon content is constant; and what when the carbon content is varied while the vanadium percentage is constant?
4. What are the magnetic properties of molybdenum steel when the percentage of molybdenum is varied while the carbon content is constant; and what when the carbon content is varied while the molybdenum percentage is constant?
5. Whether there is any relation, either in a high carbon steel or in a tungsten steel, between the ductility or the surface hardness and the residual magnetism?
6. What ratio of length to diameter is best for bar magnets made of some standard brand of tungsten steel?
7. Whether the transition temperature at which the steel regains its magnetic properties corresponds, in high-tungsten or medium-tungsten steels, to Ar_2 or to Ar_1?
8. Whether in high-tungsten steels the magnetic qualities are improved by a brief preliminary heating to temperatures between 900° and 1,200°, which are known to lower the recalescence point?
9. Whether any of the self-hardening steels of commerce are superior to the standard brands of tungsten steel in respect of remanence or of coercive force?
10. What, in the case of bar magnets made of any standard brand of tungsten steel, are the results upon the remanence and on the coercive force of maturing the magnets by prolonged heating in steam, as in the researches of Barus and Strouhal on carbon steel?
11. What are the values of the coefficients of self-demagnetization of horse-shoe magnets, and of those forms of magnet which are used in electricity meters?
12. What are the values of the temperature-coefficients for properly matured magnets of nearly-closed shapes, made of some standard brand of tungsten steel?

13. Whether, and in what way, the coercive force of a properly matured bar magnet, made of some standard brand of tungsten steel, depends upon the intensity of the field in which it was magnetized, or on the length of time during which it was subjected to that field ?
14. What are the magnetic properties of ferro-tungsten, of ferro-molybdenum, and ferro-vanadium purified from the presence of carbon, silicon, manganese, sulphur, and phosphorus?
15. Whether, in a steel or pearlitic composition if heated to 700° and allowed to cool very slowly to 670° while in a strong magnetic field, the presence of the magnetizing forces will have any effect on the formation of the pearlitic structure?
16. Effects of physical treatment:—
    (*a*) Distortion of specimens as a result of quenching.
    (*b*) Loss of magnetism as a result of vibration.

INSULATING OILS.

Section A.—Chemical.

1. In any given transformer oil what is the relation between temperature and tendency to sludge formation in any oil exposed to the atmosphere ?
2. Under abnormal conditions of specially high temperature in the laboratory what, for any given temperature, is the time required for the manifestation of sludge ?
3. What laboratory tests can be devised to determine the amount of sludge produced under abnormal conditions of specially high temperature ?
4. Whether the tendency to form sludge occasioned by high temperature and dry air or oxygen at one point can be neutralized by artificial cooling at another at any defined working temperatures ?
5. Whether the tendency to form sludge can be neutralized by keeping the surface of the oil in contact with an inert gas such as nitrogen or carbon dioxide ?

Physical.

6. Under normal working conditions what period elapses before the tendency to sludge formation is manifested in high-tension transformers ?
7. What changes in viscosity, specific gravity, flash-point, relative thermal transference, dielectric strength, and specific resistance, accompany the formation of sludge ?
8. How are the electrical properties of the oils and the formation of sludge affected by the circulation of air over their surfaces ?
9. What is the temperature to which different oils can be raised repeatedly without appreciable change in their physical properties ?

Chemical and Physical.

10. How do oils of different specific gravities and viscosities compare as to their liability to form sludge at temperatures of, say, 60, 70, 75, 80, 85, and 90 per cent of their initial flash-point ?

Section B.—Chemical.

11. What is the amount of moisture which can be absorbed from the atmosphere by a dry oil at various temperatures, and how should such increment of moisture be determined ?
12. What chemical or physical standard should be laid down as constituting a dry oil, and what changes in specific resistance and dielectric strength accompany increments in moisture ?

Section C.—Chemical.

13. Did the usually accepted tests for the detection of acid, alkali, sulphur, resin, or resinoid materials lead to comparable results ?

Physical.

14. In determining dielectric strength and insulation resistance what apparatus should be employed, how are different methods comparable, and what standard conditions, such as shape of electrodes, intervening distance, depth of immersion, movement, if any, of oil, etc., should be adopted ?

Section D.—Physical.

15. Whether any practical means are in vogue for the laboratory estimation of the relative thermal transference in switch and transformer oils, what standard apparatus should be employed for such a purpose, and by what means should this property be expressed ?
16. Is it at present possible to express the relative thermal transference of any oil at, say, 50°, 60°, 65°, 70°, and 75° C. as a function of its specific gravity and viscosity at these temperatures ?

Section E.—Chemical.

17. What is the chemical composition of the gases (known to be highly explosive) which are liberated by an arc, and does their composition vary with different mineral oils ?

Chemical and Physical.

18. Whether, and if so to what extent, the amount of carbon produced by an arc under any given oil varies with the temperature of that oil, or whether the temperature being kept constant, the amount of carbon produced varies with the specific gravity or viscosity of the oil, and if so, to what extent ?

Section F.—Chemical.

19. Whether the production of traces of nitric acid or ozone by a silent discharge at the terminals of, say, 80,000- or 100,000-volt transformers causes any change in the chemical constitution of an oil in its vicinity or may render the oil more liable to absorb moisture from the air with which its surface is in contact ?

THE HEATING OF BURIED CABLES.

An investigation to determine the temperature rise in, and the permissible current density for, buried cables.

THE JOURNAL OF
The Institution of Electrical Engineers

Vol. 52. **15 DECEMBER, 1913.** **No. 224.**

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF THE 27TH NOVEMBER, 1913.

Proceedings of the 557th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 27th November, 1913—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 13th November, 1913, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

Messrs. W. A. Mackenzie and H. C. Channon were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Members.

Dawson, William Francis.
Thomas, Eustace.

Associate Members.

Allsopp, Charles Edward.
Bailey, David Edward.
Brooks, James Illingworth.
Bruty, Albert George.
Colin, Julius.
Davies, Herbert Abram.
Erlang, Agner Krarup.
Fairgrieve, William Augustine.
Hall, Frederick Charles.
Haslam, Lionel Frank.
Heath, William George.
Hendrey, William Graeme.
Herbert, Charles Meredydd.
Hurlblatt, Douglas Gray.
Inglis, Malcolm MacKinnon.
Ingouville, Pedro.
King, Zunglich Dong.
Lawson, Wilfrid.
Licence, Francis Gilbert.
McArthur, Archie Wallace C.
Makins, Charles George G.
Morris, William Henry.
Mountain, Kenneth Arthur.
O'Brien, Claude Conroy.
Palmer, Charles Reginald.
Plank, Charles Selwood.
Pond, Thomas Arthur.
Preston, Frank Bennett.
Richards, Gilbert Howard.
Rouard, Louis Jean.
Simon, Horace Francis.
Starkey, Harold Augustus.
Stone, Harry.
Stuckenschmidt, Friedrich Georg.
Suggate, Chenery.
Warwick, John.

Associates.

Freeman, Horace.
Punter, James William.

Graduates.

Chatterjee, Bhim Chandra.
Coleman, Herbert Stoddard.
Das, Bhubanananda.
Goldthorp, Guy.
Keady, Thomas Pakenham.
Leggett, Bernard John.
Leivesley, Herbert.
Pearce, Charles William.
Pillai, N. S.
Rennick, Herbert Cumming.
Skittrall, Charles James H.
Taylor, Herbert.

Students.

Allen, Edwin.
Anderson, Sydney Drummond.
Baldwin, Sydney James W.
Barratt, John.
Bly, Harold Alfred E.
Brandrich, James.
Burton, Robert Griffiths.
Cable, Walter Henry.
Carter, Frank.
Curtis, Hugh Harry.
Damant, Edward Lorraine.
Deacon, Edwin Arthur.
Devonald, Norman.
Gripper, Laurence Albert.
Hall, Denis Kingston.
Hawkins, Charles Ernest.
Howe, William.
Huddleston, Charles.
James, Edwin Haliburton.
Khambhati, Natvarlal Ranchhodlal.
Lall, Nand.
Lee, John Harsant.

ELECTIONS (*continued*).

Love, Howard Kingsley.
Mackie, Arthur Perrott.
Mansell, Harold Leslie.
Menon, K. P. Padmanabha.
Midgley, Ernest.
Moody, Wilfrid.
Morris, Alfred.
Mouras, Salih.
Mowdawalla, Framroze Nusserwanji.
Obert, Ferdinand Thomas F.
O'Donovan, Daniel Edward.
Padgett, Albert Stanley.
Powell, Cuthbert Alban W.
Smith, Reginald Harold.
Todd, Albert Henry.
Walker, Brian Bruce.
Weston, Francis Stanley L.
Windle, John Brian.

TRANSFERS.

Associate Member to Member.

L'Estrange, William Mandeville E.
Michell, Frank Howard.
Nobbs, Cornelius George.
Reid, Hugh Stanier.

Associate to Member.

Darby, John Charles H.
Fuller, Leonard.
Graham, Frank.
Williams, John Edgar.

Graduate to Associate Member.

Fleming, Edgar William.
Hurry, Andrew Armstrong.

Student to Associate Member.

Carr, Frederick.
Eve, John Leonard.
Hacking, John.
Hilton, George Frederick.
Hoggett, Frank Reginald.
Hoyle, Bertram.
Sale, Walter Ernest.
Whitehead, Sydney Norman C. K.

Student to Graduate.

Dees, Bernard.
Fahmy, Sayed.
Gomes, José Vaz Monteiro.
Modi, Ardeshir Kaikobad.
Sadick, Mehmed.
Turner, Edward Falkland.

A paper by Mr. S. Evershed, Member, entitled "The Characteristics of Insulation Resistance" (see page 51), was read and discussed, and the meeting adjourned at 10.10 p.m.

ORDINARY MEETING OF THE 4TH DECEMBER, 1913.

Proceedings of the 558th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 4th December, 1913—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 27th November, 1913, were taken as read, and confirmed.

The President announced that the Council had elected Mr. Alexander Graham Bell an Honorary Member of the Institution.

Messrs. H. W. Ridley and T. Stevens were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Member.

Allen, Willie Pontifex.

Associate Members.

Collins, Dudley Stuart, Capt. R.E.
Gardiner, Bernard Calwoodley, Capt. R.M.L.I.
Toogood, Hubert de Chain, Lieut. R.E.

Graduates.

Carter, Herbert Dudley.
Hume-Williams, Roger Ellis.
Wall, William George P.

Students.

Angus, Thomas Cochrane.
Ballard, Frederick Leslie.
De Moura, Silvio Neves.
Dewhurst, Melbourne.
Fruhe-Sutcliffe, Reginald.
Lane, Cyril Frank.
Parikh, Jekisondas Mohanlal.
Parry, Claude William.
Reynolds, Oswald Bertram.
Young, William.

TRANSFERS.

Student to Associate Member.

Pradhan, Balkrishna Bhasker.

Student to Associate.

Carney, Henry Ambrose.

Student to Graduate.

Price, Howard.

Donations to the *Library* were announced as having been received since the last meeting from Allgemeine Elektricitäts Gesellschaft, J. Hallinger, C. H. Merz, Messrs. Siemens Brothers Dynamo Works, Ltd., and C. F. Smith ; and to the *Museum* from F. Gill, to whom the thanks of the meeting were duly accorded.

An address entitled "Electricity Supply of Large Cities" was delivered by Professor G. Klingenberg, Dr. phil., and the subject was discussed. The meeting adjourned at 10.15 p.m.

THE CHARACTERISTICS OF INSULATION RESISTANCE.

By S. EVERSHED, Member.

(*Paper first received 2nd June, and in final form 10th September*, 1913; *read before* THE INSTITUTION *27th November, before the* BIRMINGHAM LOCAL SECTION *26th November, before the* WESTERN LOCAL SECTION *1st December, and before the* MANCHESTER LOCAL SECTION *2nd December*, 1913.)

SYNOPSIS.

1. INTRODUCTORY.

During recent years a great deal of valuable research work has been done to increase our knowledge of the properties of insulating materials, yet notwithstanding the progress so made the natural laws governing insulation resistance are but little understood. So little, that if at the outset of this paper a plausible statement were made to the effect that the insulation resistance of an electrical system depended mainly upon the dielectric properties of the insulating materials, it might easily pass unchallenged. Possibly some objectors might be found among those who have to maintain the insulation of electrical plant; for no one who has had much experience of the behaviour of insulation in practice, could fail to be struck by the disparity between insulating materials under test in the laboratory and the same materials under the ordinary conditions of use.

It is, of course, easy to guess that the disparity is generally due to the presence of moisture, and in fact the only insulating materials whose behaviour in use corresponds with their predetermined dielectric properties are those which are non-absorbent. Of the remainder, and they form the majority of the materials in common use, we can only predict that the insulation resistance of any electrical system in which they are used will be governed almost entirely by the moisture they absorb. Everyone knows that insulation resistance decreases on a damp day and recovers during dry weather. It is perhaps not so generally known that in most cases insulation resistance decreases, in a perfectly definite way and almost instantaneously, as the electric pressure upon it is increased, and slowly recovers if the pressure is restored to the initial value or cut off altogether.* The connection between these two facts is by no means obvious, yet they are so closely related that if we succeed in explaining one of them we shall certainly understand the other. It is often useful to attempt to explain familiar things; facts which, like the effect of a damp day on insulation, are so natural as to require no explanation—until we begin to think about them.

The effect of moisture, the effect of voltage, the effect of polarity, these and other phenomena commonly met with in insulation have been forced upon the author's attention for many years past, and the pressing need to find answers to the questions that so frequently arise in connection with insulating materials induced him to undertake an experimental research with a view to the better understanding of their behaviour in everyday use. This work has been in progress for three years, most of the time being spent in finding a firm basis for future work. But certain experiments have already thrown some light on matters which have hitherto been obscure, and the object of this paper is to render the knowledge so gained available for all those who are interested in the insulation of electrical plant. The specialist will find herein much with which he is well acquainted; but insulation largely concerns those who have no special knowledge about it, and on that account many things have been introduced into this paper in order to give a general view of the subject.

What is the margin between the working voltage and breakdown? That is the fundamental question at the root of every inquiry into the properties of insulation. If a definite answer is ever forthcoming, it will not have been found in "blind" tests of breakdown voltage. To conduct tests without any means for ascertaining what is going on in the insulator as the breakdown voltage is approached, without either observing the current or, better still, the resistance, is to shut our eyes and deliberately avoid looking for the cause of failure.† The author has therefore sought, by investigating the nature of leakage conduction, to establish some definite relation between applied potential difference and insulation resistance. If the curve expressing this relation be traced from a few volts up to

* Since the first half of this paper was written, Mr. P. R. Friedlaender has drawn attention to the relation between voltage and insulation resistance, and has given a typical example in the form of a curve. (Communicated remarks in the discussion on Mr. Rayner's paper on "High-voltage Tests and Energy Losses in Insulating Materials." *Journal I.E.E.*, vol. 49, p. 79, 1912.)

† The flash test as applied to some costly piece of electrical apparatus must have been inspired originally by something akin to the heroism of the savage.

the breakdown point, it will be found to consist in general of two parts of opposite curvature more or less like the voltage-resistance curve shown in Fig. 1. The two parts of the curve will be joined together by an approximately straight line, the length of which varies greatly according to the nature and condition of the insulation. This connecting link is sometimes so short that the two parts of the curve appear to meet at a point of inflexion and they then form a sort of ogee curve.

The research had not proceeded very far before it was realized that the shape of the first part of this characteristic curve is determined by the extent to which leakage is due to moisture, and further that leakage through the substance

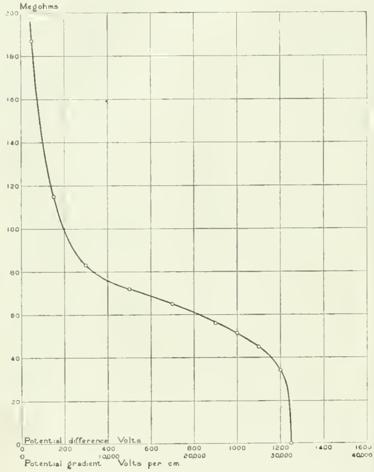

FIG. 1.—Complete characteristic curve for Cotton containing a normal amount of moisture absorbed from the air.

of the insulator—dielectric leakage—was negligibly small compared with that caused by the merest trace of moisture. This leads to the point of view that for most practical purposes an insulator may be regarded as having no inherent conductivity, the conducting power which it appears to possess being usually caused by leakage over damp surfaces. If the insulator is porous then the leakage surfaces are not only those outside the insulating body but those surfaces which bound the maze of capillary channels inside the porous material. If this idea be provisionally accepted at the outset the facts brought out by the experiments will be found to fall easily into their places, and a fairly consistent view of leakage conduction will be obtained. The research divided itself quite naturally into two parts corresponding to the two significant parts of the characteristic curve. The investigation of the second or breakdown part of the complete curve (see Fig. 1) is still in the preliminary stage, and the present paper deals mainly with the first part up to the point or region of inflexion.

2. Method of Investigation.

To avoid encumbering the paper, methods of experiment will only be described so far as they are essential. As a preliminary, a few words must be said here in order to remove any misapprehension as to what it is that goes by the name "insulation resistance." When a conductor resistance is measured care is taken to avoid the introduction of any extraneous electromotive forces due to polarization, induction, capacity, or thermo-electric junctions. By so doing, the result of the test is a true measure of an inherent property of the conductor, namely the ohmic resistance apart from any other kind of resistance or opposition to the passage of an electric current. But with insulating materials similar precautions are not generally possible, and all that can be done is to measure the ratio of applied potential difference to the resulting current, V/I, and call that the insulation resistance. We may measure the two factors either separately by means of a voltmeter and a galvanometer, doing the division sum ourselves; or both may be measured at once by an ohmmeter which does the division sum for us. Either way the result is the ratio of pressure to current. It is customary to express this ratio in ohms or megohms, and there is no harm in doing so provided we realize that the "ohms" so obtained are not necessarily of the same nature as the ohms in a metallic conductor. Of course the true ohmic resistance of the insulator (if it has such a property) is included in the result of a resistance test, but it is so entangled with surface leakage, the effects of electrostatic capacity, and the penetration of electric charges into the substance of the insulator, that we are often obliged to be content to lump all these things together when we undertake the measurement of insulation resistance.

Resistances of very high value are often measured by charging the system under test and then observing the gradual fall of potential as the charge leaks away. But this method, being based on the assumption that the resistance of an insulator is independent of the potential difference, begs one of the principal questions the author set out to answer. Obviously it was essential to measure either the resistance or the leakage current.

In dealing with so unstable a quantity as insulation resistance there are obvious advantages in making direct measurements of resistance, and perhaps the greatest advantage of the ohmmeter method is the detection of instability immediately it occurs. But it was desirable to have the means of measuring up to about one million megohms at 500 volts, and at present the galvanometer is the only instrument possessing the required sensibility. The use of ohmmeters was therefore confined to tests which came well within their range, and the greater part of the work was done by means of a Broca galvanometer made by the Cambridge Scientific Instrument Company.

The galvanometer method gives no evidence of instability until the ratios of pressure to current are worked out at the conclusion of a series of tests, and the consequence of this lack of timely warning was that in many cases it proved to be impossible to plot a curve from the observations, just because the insulation had been in an unsteady condition

during the tests. For this reason alone much fruitless labour would have been avoided had it been possible to use an ohmmeter throughout the investigation.

The pressure was supplied by a battery of secondary cells giving about 500 volts, and in a few cases this was supplemented by a small testing generator giving 1,000 volts. It should be mentioned that when leakage conduction is to be detected or measured, continuous current is essential. Quite apart from the greatly inferior sensibility of alternate-current instruments, the alternating current due to electrostatic capacity is generally much larger than the leakage current, so that the latter is difficult to disentangle and easily escapes detection altogether. Methods have been suggested by which the two currents might be separated and what is now impracticable may one day come into use, but at present continuous current has no competitor in this field.

Guarded insulation—the method of Price's guard wire extended to include every material insulating point in the testing apparatus—is now universal in insulation testing. This happy invention was of course used throughout the present investigation, and hence the current measured was in every case the current it was intended to observe and nothing else.

Before quitting the subject of methods of experiment, a minor precaution may be referred to. Every insulator has some electrostatic capacity, however small. In most cases it was inappreciable and the charging current could be ignored. But in every case in which a charging current

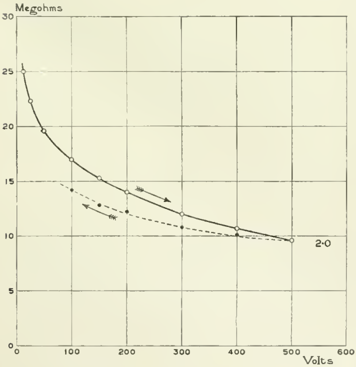

FIG. 2.—Insulation resistance of a Dynamo Armature, showing hysteresis effect.

was observed, ample time was allowed for it to die away to a negligible value before taking a reading of the leakage current.

Electrical measurement is capable of such precision that it was not easy to avoid aiming too high in this respect. Upon the whole the precision of the apparatus was much greater than the nature of the investigation required. The discrepancies that frequently occurred were almost entirely due to rapid and unavoidable changes in the insulator under test. Hence the accuracy of any set of tests was

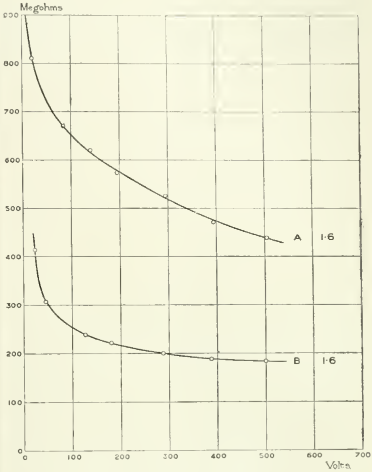

FIG. 3.—Insulation resistance of Field Coils: A, in dry weather; B, on a damp day.

often a matter of luck, and it was only upon a general review of a large number of similar tests that any sound conclusions could be reached. These remarks are all the more necessary because it is no uncommon thing to see insulation resistance expressed by a long row of figures, of which perhaps the first digit has something to do with the leakage current (and often much more to do with the charging current) and all the others have obviously been born of the slide rule.

3. Typical Examples of Insulation.

Although it is impossible to predict the insulation resistance of any piece of apparatus, yet if each of the insulating materials had a resistance as constant as that of a metal we might reasonably expect the insulation as a whole to follow Ohm's law. A few typical examples will show how little ground there is for any such expectation. In the choice of examples it does not matter what kind of insulators are involved; so long as their resistance is within the range of measurement they will nearly all tell the same tale of a gradual fall in the resistance as the testing voltage is increased. Characteristic voltage-resistance curves, obtained from things which happened to be at hand, are given in Figs. 2 to 7.

It will be seen that in every case the resistance falls as the potential difference rises, although the curves differ in shape a good deal and the decrease in the resistance is therefore much less marked in some cases than in others. It will be shown later on that these obvious variations in the curves indicate differences both in the kind of material used for insulation and the condition as regards moisture. For example Fig. 2 is a typical moisture curve, indicating that the insulation is entirely composed of absorbent

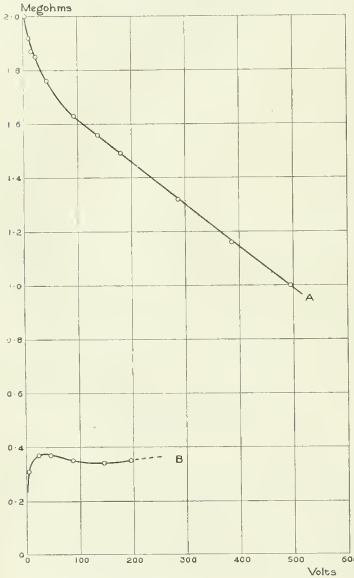

Fig. 4.—Insulation resistance of Lighting Circuits : A, in dry weather ; B, in very wet weather.

materials. It is important to note that when the curve was retraced backwards a kind of hysteresis effect appeared. With absorbent insulators this effect is nearly always to be found if one chooses to look for it. The two curves in Fig. 4, one traced on a wet day and the other after a spell of dry weather, show that a large excess of moisture not only lowers the general level of the resistance but also brings about an entire change in the character of the curve. In the lower curve three things which are characteristic of conduction by moisture are struggling for the mastery. On a wet day every solid insulator is covered with a film of water which if it were in stable equilibrium would conduct according to Ohm's law and give a horizontal straight line. But instability is a marked feature of films when they are exposed to the air, and hence in practice the curve is never a simple straight line. In addition there is some typical

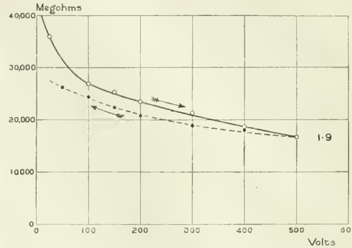

Fig. 5.—Insulation resistance of a moving-coil Ammeter in which the ebonite insulation had become defective from an accumulation of dirt.

conduction through absorbent insulators, and the curve is the resultant of all three effects.

In Fig. 5 the resistance was in an unstable condition, several discrepancies being noticed in the course of the tests. This curve being retraced backwards from 500 volts also shows the hysteresis effect.

The curve in Fig. 6 is typical of insulation that is made up of an absorbent insulator in series with one which has a more nearly constant resistance, and when the nature of moisture conduction has been examined we shall see how the resistance of these two components may be separated and an approximate value assigned to each. In short, we shall arrive at the tentative beginnings of a rough diagnosis of insulation. Fig. 7 is remarkable because it shows that the resistance was affected by polarity. When the testing

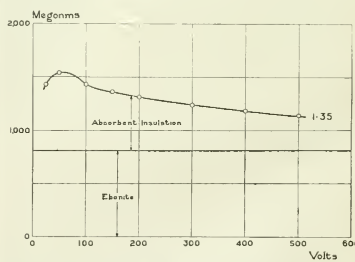

Fig. 6.—Insulation resistance of a Supply Meter, a typical example of absorbent insulation in series with a non-absorbent insulator.

generator was so connected that the circuit wires were positive and the earth negative, the resistance was 8·7 megohms; whereas when the polarity was reversed the

resistance fell to 5·7 megohms; both readings being those taken at 500 volts.

The polarity effect which has just been noticed in connection with Fig. 7 is a strongly marked characteristic of earthenware insulators, and although it has nothing to do with the characteristic curve some account of it seems to be called for in a paper on insulation resistance. But the subject cannot be dismissed in a few lines and to avoid a long interruption in our main argument the effect of polarity has been dealt with in an appendix under the heading "Insulation Valves." The matter is one which closely concerns everyone who has occasion to test insulation in which earthenware of any kind is used as an insulator.

Before any general hypothesis can be framed to account for the characteristic behaviour of insulation in ordinary

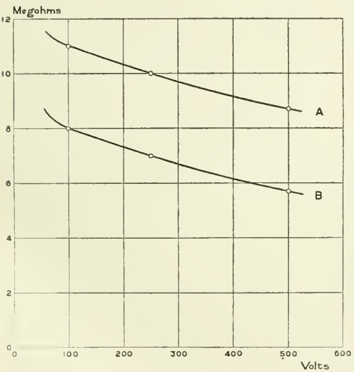

FIG. 7.—Insulation resistance of Interior Wiring, showing polarity, or "valve," effect (Ohmmeter test).

A. with wires *positive*, earth *negative*.
B. with wires *negative*, earth *positive*.

use, it is clearly necessary to know something about the individual behaviour of different insulating materials. For this purpose a brief outline will be given of the prolonged experiments that were made on a large number of materials which are in common use for insulating purposes. The materials included rubber, gutta-percha, micanite, porcelain, cotton, paper, silk, oils, and varnishes. Not a tithe of the work done can be recorded here, but it will be sufficient to describe a few of the more important experiments made on insulators which are typical of their class.

4. DIELECTRIC RESISTANCE.

Our object being to learn something about conduction through moisture, any dielectric leakage there may be through the substance of the insulators can only be ignored if we first show that dielectric resistance is enormous in comparison with the resistance of the leakage paths which are formed by traces of moisture.

Figures may be found in the text-books for the specific resistance of various insulators. What may be called good insulators vary from about 80 million megohms for mica up to about 50,000 million megohms for vulcanized rubber—the centimetre cube being the datum. Such figures as these convey no more meaning to the mind than the distance of a star expressed in miles; we do not want figures so much as relative magnitudes. The consideration of an example of dielectric conduction will therefore be a useful preliminary because it will afford some insight into a subject which is but little understood outside the test room, and at the same time serve to create a proper sense of proportion.

The only non-absorbent insulators which were tested in the course of the work recorded here were gutta-percha and rubber. These are both non-absorbent in the sense that what little water they may be capable of absorbing is entirely unable to form leakage paths through the insulator. Submarine cables insulated with these materials have been lying on the bottom of the sea for half a century or more, and, so far as the author is aware, no trace of conduction by absorbed water has ever been detected in a sound cable.

Rubber as an insulator for cables is so extensively used in every branch of electrical industry that it is naturally the example chosen for illustration. The test sample was a rubber-covered flexible cable made up of 64 6-mil wires, insulated in accordance with the standards of the Cable Makers' Association, and guaranteed to have an insulation resistance of not less than 600 megohms for one mile after one minute's electrification. The rubber is between 35 and 37 mils in thickness, and consists of one layer of pure Para and two layers of vulcanized rubber. This flexible is used by the author's firm for the interior connections of naval gear and for that purpose it is supplied without any covering outside the rubber; it was therefore in suitable form for an under-water test. A length of this cable—equal to $\frac{1}{16}$th of a mile—was put into a bucket of water, where it remained for 40 days. The tests which were made during that period consisted in charging the cable at about 500 volts and observing the total current flowing into it at intervals of time, so that a time-current curve might be drawn. Tests were also made by discharging the cable and observing that part of the discharge current which passed out through the galvanometer. It should be noted that whereas during the charging of the cable the entire charging current traverses the galvanometer, no equivalent statement can be made about the discharge current. During discharge there are three parallel paths for the current: through the galvanometer, through surface leakage paths at the exposed ends of the cable (the guard wires being ineffective during discharge), and lastly the dielectric leakage paths through the rubber. Hence the discharge as recorded by the galvanometer does not agree exactly with the charge.*

Suppose the cable is charged through a resistance of r megohms by a battery giving V volts, the dielectric resistance being R megohms. Then the leakage current will be $V/(R + r)$ micro-amperes, and the initial value of

* For the purpose of this paper it is not necessary to describe the ordinary method by which the leakage current is arrived at by deducting the discharge current from the total current flowing into the cable.

the charging current will be V/r micro-amperes. The charging current dies away, rapidly at first then more and more slowly. Ultimately, possibly after many hours, it will have fallen to a value which cannot be distinguished from zero, and the only appreciable current passing through the galvanometer will be the true dielectric leakage, namely $V/(R + r) = I$. Since R is always very large compared with r the latter may be

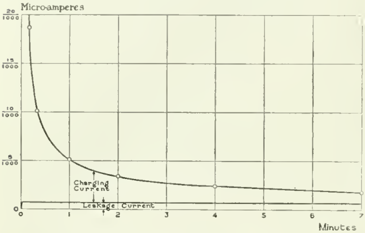

FIG. 8.—Leakage current plus charging current flowing into a rubber cable, from 0 up to 7 minutes.

neglected and V/I will correctly express the dielectric resistance at voltage V—provided the patience of the observer has not been exhausted before the final subsidence of the charging current to zero. The actual result of a test of this kind, made after the flexible had been in the water for 10 days, is shown in Figs. 8 and 9. In Fig. 8 the time-current curve is given from 10 seconds up to 7 minutes after the closing of the charging circuit; while Fig. 9 shows the same curve from 3 minutes up to 420 minutes (7 hours).

Incidentally these two diagrams afford a good illustration of the misleading appearance of curves of this class. Judging from Fig. 8, one would infer that within 4 or 5 minutes the current was already nearly approaching its final steady value: "Well round the bend of the curve" is a phrase often used in this connection. But we have only to change the time scale from minutes into hours, and magnify the current scale by a substantial amount, and the curve conveys a very different impression. Looking at Fig. 9, and again judging by eye, we now draw the inference that instead of a few minutes an hour or more must elapse before the current can be said to be "well round the bend of the curve."

The charge was continued for 27 hours without a break, and by that time the current had fallen to 0·00072 micro-amperes at 525 volts. This was assumed to be the true dielectric leakage current and its value is indicated on each of the diagrams by a horizontal line, in order that the relative magnitudes of charging current and leakage current may be seen at a glance.

It has been the custom ever since the early days of submarine telegraphy to observe the total current at the end of the first minute, and to call the ratio of the charging voltage to that current "the insulation resistance after one minute's electrification," a custom which is still adhered to by cable-makers. Inspection of the curve in Fig. 8 shows that at one minute 86 per cent of the total current was charging current, only 14 per cent being true leakage current. Hence when a cable-maker specifies the resistance of cable similar to this as so many megohms, his statement only contains 14 per cent of the whole truth. Economy of truth, however, is on the side of honesty in this instance, and the buyer is doubtless aware of the customary method and sometimes understands what it implies.

In this paper we are more concerned with fact than custom. Fig. 8 shows that at one minute the total current was 0·0051 micro-amperes at 525 volts, hence the value of what may be called the "customary resistance" was $525/0{\cdot}0051 = 103{,}000$ "megohms" for $\frac{1}{16}$th of a mile of cable; and the customary resistance of one mile of similar cable would be 103,000/16, or roughly 6,000 "megohms." The final value of the current being 0·00072 micro-amperes, the real dielectric resistance was $525/0{\cdot}00072 = 730{,}000$ megohms for $\frac{1}{16}$th of a mile, equivalent to a dielectric resistance of 45,000 megohms for one mile of similar cable.

With these figures as a guide let us ascertain the relative importance of dielectric leakage and moisture leakage in some installation of interior wiring in which rubber insulated wires are used. The circuits which gave the characteristic curve shown in Fig. 7 afford a good example, being carried out with rubber-covered wire insulated to the same standard as the flexible we have just examined. The conductors also are of the same diameter in the two cases. The installation contains 380 yards of wire, coupled up in the usual way to a number of fittings in which porcelain is used exclusively as the insulator. Assuming the covering

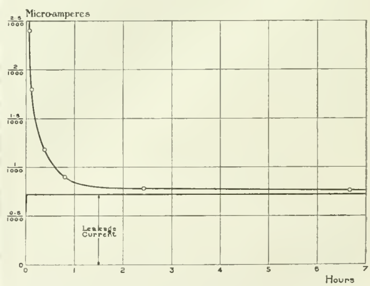

FIG. 9.—Leakage current plus charging current flowing into a rubber cable: continuation of the time-current curve in Fig. 8, up to 7 hours.

of the wires to be undamaged, the dielectric resistance of 380 yards of wire to earth will be about $45{,}000 \times \frac{1760}{380} =$ 200,000 megohms, and the customary resistance would be about $6{,}000 \times \frac{1760}{380} = 28{,}000$ "megohms." We need not attempt to decide which of these values is to be taken, because it is only necessary to look at Fig. 7 to find that the resistance of the installation as a whole was but a paltry 6 megohms, even when tested in dry weather. The relative importance is now obvious; leakage through the

dielectric rubber is nothing, leakage at the fittings is everything.*

What has been demonstrated in the case of rubber must be equally true with regard to any insulator which has a resistance in any degree comparable with that of good rubber. The resistance of such materials as ebonite, sulphur, glass, mica, gutta-percha, shellac, dry paper, and dry cotton, is in every case enormous; like rubber their specific resistance is measured by millions of megohms, and in most cases by thousands of millions. Hence dielectric leakage will be ignored in what follows. In a later section the conduction through a porous insulator is compared with the quantity of absorbed water it contained an experiment which incidentally gave another convincing proof of the relative insignificance of dielectric leakage.

5. Moisture Curves.

Cotton.—Although this material is so largely used as an insulator for wires the opportunity for observing its

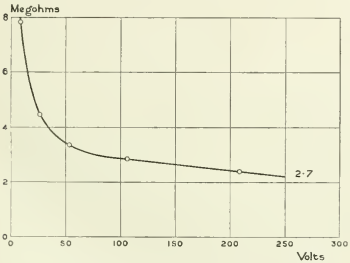

Fig. 10.—Insulation resistance of Cotton which contained a normal quantity of moisture.

resistance seldom or never arises in practice. Several test-pieces were therefore made up for the purpose, each consisting of two cotton-covered wires wound side by side in a single layer on a well glazed porcelain bobbin so that leakage from one wire to the other could only take place through the cotton coverings. One of these cotton test-pieces when tested for insulation resistance from one wire to the other gave the curve shown in Fig. 10. After being dried in an oven at 150° C. for a couple of hours, and then allowed to cool, this test-piece gave the curve shown in Figs. 11 and 12. The resistance is now five or six times greater as the result of the partial evaporation of the moisture originally contained in the cotton, but the general character of the voltage-resistance curve is unaltered. It will be noticed that at 500 volts the resistance has fallen to

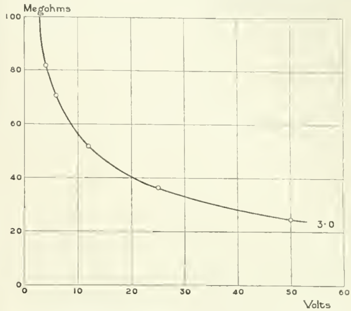

Fig. 11.—Insulation resistance of Cotton; the same test-piece as in Fig. 10, but partially dried by baking.

about one-third the value it had at 50 volts, or to put it shortly $R_{50}/R_{500} = 3$.* This is a rough-and-ready way of comparing curves which, although following similar laws, look very different to the eye simply because they are plotted to different scales. In the diagrams the value of the ratio R_v/R_{10v} is marked at the end of each characteristic curve so that different curves may be readily compared, and it will be found as we proceed that in the case of absorbent materials this ratio is more commonly nearer 2 than 3. After further drying at 150° C. for some hours, this

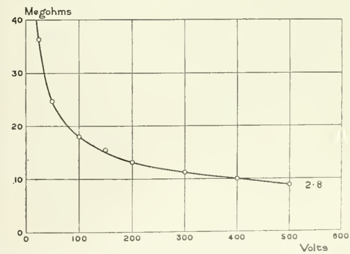

Fig. 12.—Insulation resistance of Cotton; continuation of the curve in Fig. 11 up to 500 volts.

same test-piece gave the curve shown in Fig. 13. The effect of the drying process has been to increase the resistance to something like 80 times the initial value, but

* It may be remarked in passing that the average resistance per leakage point is a useful criterion for the insulation of wiring. In the case of the resistance from wires to earth, the switches, fuse-blocks, ceiling roses, lampholders (if they can leak to earth), and other places where the conductors are fastened to leaky insulators, constitute the leakage points. For resistance between the wires with the switches closed and the lamps removed, the lampholders alone are to be counted; and for resistance between the wires with the lamps in place and the switches open, the switches are the only leakage points that count.

In the example considered in the text the resistance to earth was about 6 megohms, and there were 62 leakage points, hence the average resistance per leakage point was $6 \times 62 = 372$ megohms. Remembering that one switch base of good quality may have a resistance as low as 100 megohms, it is evident that the installation as a whole was in excellent condition as regards insulation.

Rules based solely upon the number of lamps are frequently too remote from the facts to afford much guidance.

* The exact value of the ratio is 2·8 in this example.

notwithstanding the great diminution in the quantity of water in the cotton, the curve retains the characteristic shape. The reason for this remarkable persistence in the law of moisture conduction under widely varying conditions will be found in a later section.

Paper.—Although cotton exhibits all the phenomena of conduction by moisture, it is not the most convenient material for experiment. Paper lends itself very much better to exact conditions as regards the area and length of the insulator interposed between the two conductors. Various kinds of paper under a variety of conditions as regards moisture, compression, length, and area, were exhaustively tested. The test-pieces were each composed of several sheets of paper cut to a suitable size and shape and laid in a pile on a flat copper plate which served as one electrode. A second copper plate on the top of the pile of paper acted as the other electrode, and by putting the complete test-piece in a small screw press any compression could be obtained, from that due to the weight of the upper electrode to about 100 lb. per square inch. As might be expected, paper behaves in much the same way as cotton. The two curves shown in Figs. 14 and 15 were obtained from drawing paper of good quality. In both cases the paper was in a normal state as regards moisture.

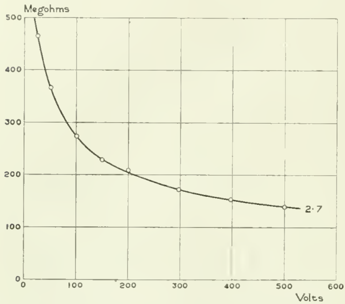

FIG. 13.—Insulation resistance of Cotton; the same test-piece as in Figs. 10, 11, and 12, after further baking.

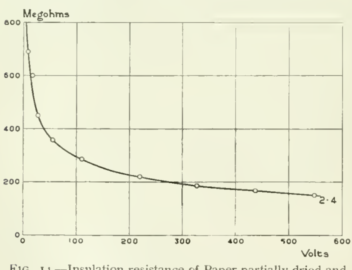

FIG. 14.—Insulation resistance of Paper partially dried and tested at a compression of 2·8 lb. per sq. inch.

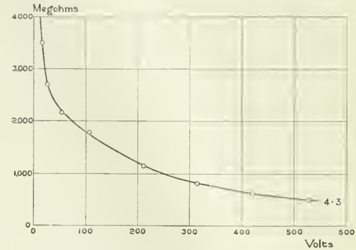

FIG. 15.—Insulation resistance of Paper; the same test-piece as in Fig. 14, but tested at 0·1 lb. per sq. inch.

The law of the characteristic curve is considerably affected by the degree of compression to which the absorbent material is subjected. The curve in Fig. 14 corresponds with a pressure of 2·8 lb. per square inch, whereas in the case of Fig. 15 the pressure was only 0·1 lb. per square inch. The corresponding values of the ratio R_{50}/R_{500} were 2·4 and 4·3. The latter figure is abnormally high and nothing approaching it has been observed in any tests of insulation under working conditions, probably because in practice absorbent insulators are always under a greater mechanical pressure. In Fig. 16 the connection between compression and the ratio $R_v/R_{10\,v}$ is traced from zero up to 40 lb. per square inch.

The degree of moisture in an absorbent material, like paper, may be varied within wide limits without much affecting the law of the moisture curve, although the corresponding variations in the resistance will be enormous. But when the material contains a considerable excess of moisture, so that it is sensibly damp, the law

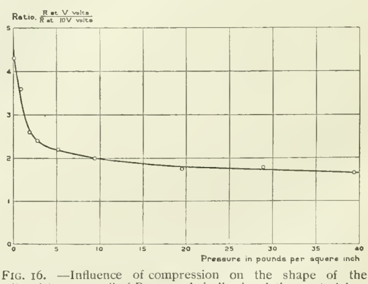

FIG. 16. —Influence of compression on the shape of the "moisture curve" of Paper and similar insulating materials.

begins to change; the ratio R : R gradually approaching unity as a limit and the curve subsiding into a horizontal straight line. In other words when an absorbent insulator

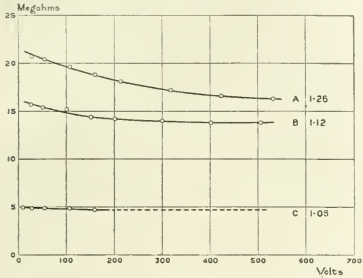

FIG. 17.—Moisture curves of damp Paper showing gradual change from moisture conduction to Ohm's law as the Paper becomes sodden with water.

is sodden with water its resistance follows Ohm's law. This gradual change from a moisture curve is illustrated in Fig. 17, the curves being obtained from paper in which increasing quantities of water had been absorbed. Owing to the very low resistance of the wet paper, curve C could not be continued beyond about 160 volts.

Micanite Cloth.—The test-pieces for examining this material were made up by wrapping a single thickness of the cloth round a piece of smooth iron pipe, and then winding a single layer of cotton-covered wire tightly over it. The cloth was therefore tested under much the same

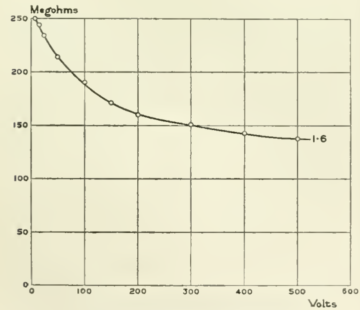

FIG. 18.—Insulation resistance of Micanite Cloth which contained moisture absorbed from the air.

conditions as are commonly met with in practice, micanite cloth being largely used as an insulator for windings. Of course in ordinary use there may be leakage over the surface of the cloth in addition to that which takes place through the insulating material; but as it was intended in these experiments to investigate conduction *through* the micanite apart from any other leakage, guard wires were tightly twisted round the cloth which projected beyond the winding at each end of the test-piece.

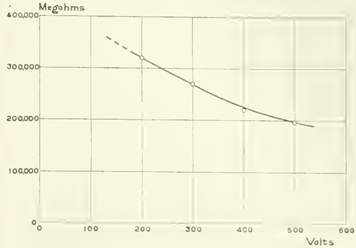

FIG. 19.—The same test-piece as in Fig. 18 tested 24 hours after being dried in an oven. *Note:* One hour after removal from the oven this test-piece had a resistance of 1,300,000 megohms at 500 volts.

One of these test-pieces, immediately after being wound and before being dried, gave the curve shown in Fig. 18. Notwithstanding the presence of the layer of mica the curve indicates conduction by moisture. The rather low

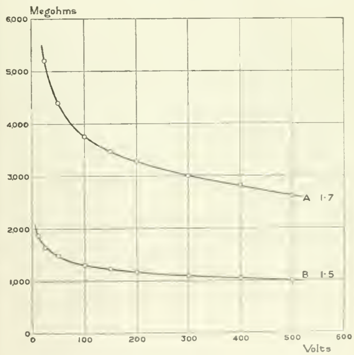

FIG. 20.—The same test-piece as in Figs. 18 and 19, tested after exposure to the air for (A) 5 days, and (B) 90 days.

resistance suggested that there was a good deal of water absorbed in the cloth, and the test-piece was therefore baked for about four hours at 150° C. In one hour after removal from the oven the test-piece was cold and its resistance was then about 1,300,000 megohms when tested at 500 volts. It was then left exposed to the air of the

experimental room in order to find out to what extent micanite cloth acted as an absorbent of atmospheric moisture. At the end of 24 hours' exposure the curve reproduced in Fig. 19 was obtained, showing that the resistance had fallen, although it was still barely within the range of easy measurement. The two curves given in Fig. 20 were obtained after exposure to the air for 5 days and 90 days respectively.

It is by no means surprising to find a laminated substance like mica acting as an absorbent body, and in the form which it necessarily takes in micanite cloth there are innumerable capillary spaces available for the formation of leakage paths. It should be noticed that in these curves the ratio R_{50}/R_{500} is much less than 2; the average value deduced from seven curves obtained from micanite cloth test-pieces is 1·47.

Many other more or less absorbent insulators might be added, but the three examples which have just been examined are typical of the whole. The composition of the insulating substance seems to be of little importance. So long as the structure of the material is such as to provide capillary spaces to harbour moisture, leakage will take place in the characteristic manner. Of course the difficulty of maintaining adequate resistance in absorbent insulators is fully realized, and they are seldom used without an attempt being made to exclude moisture by means of some non-absorbent insulator applied as an oil or a varnish and intended to close all the capillary channels. In the following sections the effect of filling up the pores of absorbent materials is dealt with in connection with oiled paper and varnished windings.

6. Conduction through Oil.

Oils are good insulators in themselves, but they are capable of absorbing traces of water. An investigation was therefore made to ascertain whether water when absorbed in oil behaved in the same way as moisture in an absorbent solid. For the purpose of the test a glass beaker was fitted up with two flat copper discs, one above the other, to act as electrodes. The upper disc was adjustable up and down by a micrometer screw so that the electrodes could be set accurately to any required distance. Several different kinds of oils and varnishes (and also liquids which are used as solvents in varnishes) were tested in this apparatus and in every case Ohm's law was followed, the resistance proving to be a constant quantity not varying with the potential difference between the electrodes. It was necessary to know whether the same thing applied to oil in which water had been absorbed. The oil used for the test was a heavy hydrocarbon sold as a lubricant for gas engine cylinders. It had the disadvantage of a rather low resistance—about 2·5 million megohms for a centimetre cube*—but it was chosen because a large store of it was available, and hence uniform samples might be relied on. A trace of distilled water was dissolved† in the oil by putting a few drops into a bottle containing a pint of oil and stirring for many hours. The oil was then left at rest for about 48 hours in order to allow the suspended water to settle down. The slightest trace of water in suspension is apt to cause instability in the resistance because all the suspended particles are slowly drawn in between the electrodes by the electrostatic force, and when there they tend to form conducting chains from one electrode to the other. The result of a test with oil containing absorbed water is shown in

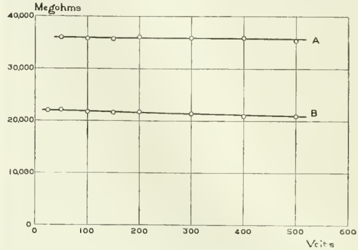

Fig. 21.—Resistance of Cylinder Oil: A, when dry; B, containing a trace of absorbed water.

Fig. 21, the upper curve being obtained from cylinder oil freshly drawn from the storage tank and the lower curve from the same oil after absorbing water. Notwithstanding some irregularity due to water in suspension, the effect of the absorbed water is evident in the marked lowering of the resistance. But of any effect like that due to moisture in absorbent solids there is no trace. In both curves the resistance is practically constant, Ohm's law being followed well enough.

7. Oil-impregnated Paper.

Paper containing moisture may be saturated with an insulating oil without producing any effect on the leakage paths formed by the water. The curve shown in Fig. 22 was obtained from drawing paper which, while in a

Fig. 22.—Insulation resistance of Paper which had been soaked in dry Cylinder Oil for a week.

normal state as regards moisture, was immersed in dry cylinder oil and left to soak for a week before being taken out and tested. The resulting curve does not differ in any way from an ordinary moisture curve, the ratio R_{50}/R_{500}

* The oil used for impregnating paper cables has a specific resistance of about 700 million megohms, at 15° C.

† The water may not be in solution in a chemical sense but it is permanently absorbed in the oil, whereas any water in suspension or forming an emulsion with the oil, ultimately separates out and falls to the bottom of the vessel.

being 2·1 for the oiled paper. It is evident that the oil does not displace the water, or break up the conducting paths, or interfere in any material way with the characteristic conduction due to the moisture which was present in the paper before the entrance of the oil.

The converse, however, does not hold good. Water will not only find its way into paper which has been dried and soaked in oil, but will so far displace the oil as to form leakage paths. As is well known, paper impregnated with oil easily absorbs water from the air. Hence the necessity for the lead covering and soldered joints of an impregnated-paper cable. To ascertain whether moisture absorbed by an impregnated paper cable was able to form leakage paths of the same kind as those in other absorbent solid materials, a short piece of lead-covered impregnated-paper cable was left with both ends open and exposed to the air of the experimental room. The curve shown in Fig. 23 was obtained when the cable had been open to the air

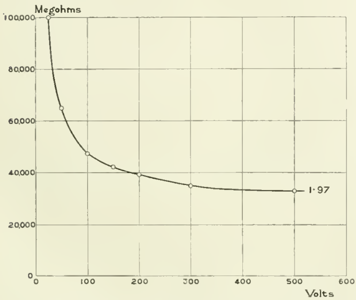

FIG. 23.—Insulation resistance of Oil-impregnated Paper Cable with the ends open, after exposure to the air of the Experimental Room for 13 months.

for 13 months. There is nothing to distinguish it from the characteristic curves of more ordinary absorbent insulators. The ratio R_{50}/R_{500} is 1·97, quite a normal value for a moisture curve when the absorbent material is under a moderate compression.

Although water ultimately finds its way into impregnated paper, the process of absorption is extraordinarily slow. The piece of paper cable when first tested had a resistance of about one million megohms at 500 volts, and although this high value was not maintained for more than a month or so, it required nearly 9,000 hours' exposure to the air to reduce the resistance to 33,000 megohms. Had the cable been insulated with dry paper (not impregnated) the resistance would have fallen to the same extent—in other words, the same quantity of water would have been absorbed—in four or five hours at the most.

The experiments on oiled paper lead irresistibly to the conclusion that the mode in which absorbed water forms conducting paths is substantially the same whether the insulator is saturated with oil or not. The water may be in the insulator before impregnation with oil or it may be very slowly absorbed afterwards, but once inside it will conduct electricity just as though the oil was not there.

8. VARNISHED WINDINGS.

Varnish is intended to prevent water from forming leakage paths. To do this it must either keep out water by closing all the pores at the external surface of the insulator, or it must interpose a solid and impervious layer of the body of the varnish between the conductors and the porous insulator. Applying varnish by a brush aims at the first alternative, vacuum methods aim at the second. It need hardly be pointed out that when a porous body is saturated with a liquid varnish, and the solvent is then dried out, the solid body of the varnish remaining in the insulator is necessarily insufficient in quantity to fill up the pores. They can only be entirely filled up by soaking the insulator in oil, or in a melted wax or in some equivalent solid insulator which can be liquefied by heat. Hence a porous insulator, even when varnished, is likely to have many channels available for the reception of water. Whether water can find its way into them depends on how far the varnish has been able to stop up the pores on the outside of the insulator.

Experiments on varnished windings occupied many months, and in several cases varnished test-pieces have been kept under observation for over two years. Their outcome can be summed up in a sentence. Varnish reduces the extent to which moisture is absorbed, but it seems powerless to stop absorption altogether if the windings are subjected to the temperature variations which occur in ordinary use. This failure to exclude moisture was exhibited in every trial, both by test-pieces varnished by a vacuum method and by those which had received coats of varnish applied by a brush. A couple of tests will illustrate the whole series.

The vacuum method consisted in first baking the test-piece at 150° C. for several hours ; then putting it into the vacuum chamber and exhausting down to a few mms. pressure ; then running in the varnish until the test-piece was completely submerged, the vacuum pump being kept going and the varnish boiling for half an hour or so. Next, air was admitted to the vacuum chamber and the test-piece was left under atmospheric pressure for an hour or more in order to give ample time for the varnish to be forced into the insulation. After this the test-piece was baked for several days at a temperature not exceeding 150° C., and after cooling, the resistance tests were begun. One of the test-pieces, composed of two cotton-covered wires wound on a porcelain bobbin, had an initial resistance of 34,000 megohms after being varnished by this method with a black plastic varnish of good quality. The resistance followed Ohm's law, being constant at all pressures up to 500 volts, thus indicating conduction by the varnish and the absence of moisture conduction. Yet after exposure to the air of the experimental room for 9 days this test-piece gave a perfectly normal moisture curve with a ratio R_{50}/R_{500} equal to 2·1, and the resistance had already fallen to less than one-fourth of the initial value. This fall in resistance and change in the law of conduction are shown in the two curves in Fig. 24. The resistance continued falling for several months and ultimately settled down round about 2 or 3 megohms, rising and falling with the changes in the humidity of the air. A striking experi-

ment was made on this test-piece by boiling some water in an open vessel in a room adjoining the experimental room. Upon opening the communicating door so as to admit air laden with water vapour, the resistance of the test-piece immediately began falling and continued doing so for half an hour. At the end of this interval the boiling

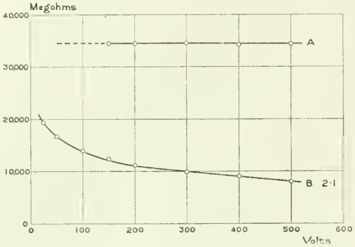

FIG. 24.—Insulation resistance of varnished Cotton: (A) 12 hours and (B) 9 days after baking. Showing the change from Ohm's law (when the test-piece was dry) to moisture conduction after a few days' exposure to the air.

water was removed and the windows of the experimental room were opened in order to restore the air to its original state. Within 3 minutes the fall ceased and the resistance began rising as steadily as it had fallen, until, in about 50 minutes from the time when the boiling water was removed, it had recovered its initial value. One could not have clearer evidence of the ease with which moisture is absorbed by a well-varnished winding.

The history of this test-piece affords a direct proof that the characteristic shape of the first part of the voltage-resistance curve is the result of leakage through moisture. In its initial state, when all moisture had been expelled by prolonged baking, we have a high resistance, and what little leakage there is follows Ohm's law because the varnish itself conducts in that way. But a few days' exposure to the air is sufficient to bring about a complete change in the mode of conduction, and in place of Ohm's law we have the characteristic curve which is common to all absorbent insulators. Finally, we see the resistance falling when the air is artificially charged with water vapour, and rising when the air is restored to its normal condition.

The other test to be described was made on one of the windings used for testing micanite cloth. Two coats of the plastic varnish were applied by a brush to the outside of the winding, and the test-piece was then baked at 150° C. for 32 hours, by which time the varnish was quite dry. After allowing the test-piece to cool, the resistance from the winding through the micanite cloth to the iron core was about a million megohms. This high value was not maintained for long. Within 20 days after removal from the oven a decrease was noticeable, and by the 74th day the resistance had fallen to 33,000 megohms. The curve obtained on that day is given in Fig. 25. It should be compared with the curves given in Fig. 20 for a similar micanite cloth test-piece which had not been varnished. Both curves indicate leakage through moisture, but the varnish has in this case greatly reduced the amount of moisture which the insulation can absorb.

There can be little doubt that the failure to exclude moisture altogether is due to insufficient elasticity in the body of the varnish. Unless this is a highly elastic substance it is unable to follow the expansions and contractions of the windings, and ultimately the continuity of the coat of varnish is broken up, leaving numerous crevices by which moisture can enter.

9. Volume of Water in the Leakage Channels.

The first stages in the investigation of any phenomena are necessarily qualitative. Arithmetical quantity only comes when an attempt is made to fit the phenomena into some kind of ordered scheme. It is difficult to apply arithmetic to so elusive a quantity as the resistance of absorbed moisture, but at this point questions naturally arise as to the volume of water which is utilized in forming leakage paths, and what sort of relation that volume bears to the total volume of water in the absorbent insulator.

To find some answer to these questions experiments were made on the resistance of an absorbent insulator containing known quantities of water of a measured specific resistance. The insulator was composed of a number of circular discs of chemically pure filter paper, 12·5 cm. in diameter, piled up into a pad and moderately compressed between two flat metal electrodes. The pad of paper had an area of 122 sq. cm., and its thickness (under the compression) was 0·53 cm., so that the pad occupied a volume of 64·8 cubic centimetres. The specific resistance of the water used in this experiment was 2,500 ohms.

To begin with, a quantity of the water was put into the

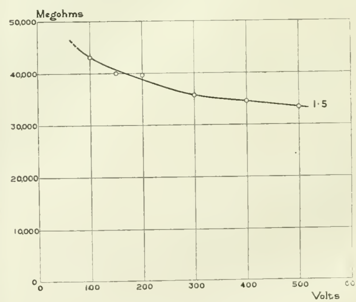

FIG. 25.—Insulation resistance of varnished Micanite Cloth (compare with Fig. 20).

paper and left to distribute itself uniformly. The method of experiment was to measure the resistance of the pad and weigh it immediately afterwards. Next, to allow some of the water to evaporate and then to repeat the resistance test and the weighing. Proceeding slowly step by step, the water was finally dried out and the net weight of the dry

paper ascertained. In this way a number of corresponding values were obtained for weight of water in the paper and resistance of the pad. The figures are given in Table I, the volume of water in cubic centimetres being taken as equal to the weight in grammes.

TABLE I.

Test-point	Volume of Water in the Pad of Paper c.c.	Resistance of the Pad at 500 volts (megohms)	Estimated Volume of *Resistance Water* c.c.	Ratio of *Resistance Water* to Total Water, expressed in Parts per million	Percentage Volume of Water in the Pad of Paper
A	1·68	93	188×10^{-6}	112	2·59
B	1·55	131	134 ,,	87	2·39
C	1·48	179	98 ,,	66	2·28
D	1·43	226	78 ,,	54	2·20
E	1·29	369	48 ,,	37	1·99
F	1·14	845	21 ,,	18	1·75
G	1·08	1,280	14 ,,	13	1·66
H	1·00	1,870	9·4 ,,	9·4	1·54
I	0·59	23,600	0·74 ,,	1·3	0·91
J	A trace	$11·7 \times 10^6$	—	—	0

Remembering that the resistance of a centimetre-cube of the water was only 2,500 ohms, it is obvious by inspection of the figures in the second and third columns that the resistance of the pad is out of all proportion to the volume of water it contains. Let us analyse one of the tests and see how the two things may be reconciled. Test H is a convenient example, because there happened to be exactly 1 cubic centimetre of water in the paper. The problem is to utilize that volume in such a way as to give the water as a whole a resistance of 1,870 megohms. We must begin by using some of it to make a conducting path of the required resistance and of sufficient length to go from one electrode to the other by a rather tortuous route; tortuous, because it must thread its way through a maze of capillary channels in the paper. Having formed the necessary resistance channels we may dispose of the rest of the cubic centimetre of water by storing it inside the paper as an entirely detached body or bodies, so that it can play no part as a conductor. By these arbitrary proceedings the water will have been divided into two very unequal portions, which may be called *resistance water* and *dormant water*.

Still dealing with Test H how much resistance water will be required to make up the observed value of 1,870 megohms? To answer this question some reasonable guess must be made at the length of the tortuous current path. Now the current will certainly take the shortest available route, and there are such an enormous number of intercommunicating channels in the paper that the average length of all the available paths is unlikely to be more than two or three times the distance between the electrodes. It would require a highly artificial arrangement of the fibres in the paper to compel the current to travel anything like ten times the shortest distance, and in the following calculation it will be assumed that the average path is five times the distance between the electrodes. The electrodes being separated by the thickness of the pad of paper—namely 0·53 cm.—the assumed average length of current paths will be 2·65 cm.*

The volume of a conductor of given resistance length and specific resistance is $\rho l^2/R$ so that at test-point H we have—

$$\text{Volume of } \textit{resistance water} = \frac{2500 \times 2{\cdot}65^2}{1870 \times 10^6} = \frac{9{\cdot}4}{10^6} \text{ c.c.}$$

Compare this volume with the total quantity of water in the paper, namely 1 c.c., and we arrive at the figure given in the fifth column of the table:—Under the conditions at Test H the proportion of resistance water to total water was only 9·4 parts in a million.

The reader will distinguish between the observed quantities recorded in the table and the figures which are the result of calculation based on certain assumptions, tacit and otherwise. Thus, the average length of the leakage paths has been assumed to be five times the distance between the electrodes; the dormant water has been assumed to occupy blind alleys entirely off the paths of the leakage current; and the conductivity of the water in the pad of paper has been assumed to remain constant notwithstanding evaporation. Let us see in what direction these assumptions affect the magnitude of the estimated volumes given in the table.

First as regards length. Since the volume of a conductor of given resistance is directly proportional to the square of its length, it is obvious that any underestimate in the length of the leakage path will result in an underestimated volume; and if we choose to double the assumed length, then the volume figures must be multiplied by 4.

Now as to the disposal of the dormant water. In Test H, the calculated volume of resistance water was $9{\cdot}4/10^6$ c.c., and the length of path 2·65 cm. Translated into more familiar units the resistance water in the innumerable leakage channels was equivalent in the aggregate to a single thread of water rather over an inch in length, and a little more than three-quarters of a mil in diameter.† Let us take some of the dormant water and distribute it along this thread in the form of detached drops, like dew on a spider's web. Each drop, owing to its comparatively large volume, short-circuits the portion of thread to which it clings. To fix our ideas, we can suppose the drops occupy half the entire length of thread and therefore reduce the resistance to one-half. To bring up the resistance to the observed value it will be necessary to reduce the sectional area of the remainder of the thread by one-half, and that part of the leakage path which remains effective as resistance will now have a volume equal to one-quarter of the value reckoned on the assumption that dormant water might be left out of account. It is clear,

* Let the engineer who has never used a factor of safety cast the first stone at this arithmetic.

† At test-point I, the thread of water, which is the equivalent of all the leakage paths, had been reduced to less than one-quarter of a mil in diameter.

then, that this assumption leads to an overestimate of volume, and if the whole of the dormant water is shunted into sidings or blind alleys the volume of resistance water as calculated from the observed resistance is overestimated to the maximum extent.

The drops of dormant water which we have supposed to be distributed along the path of the leakage current might just as well be collected together to form one or more larger bodies of water. The principle is the same, and all we have to bear in mind is that the length of resistance thread which remains intact will be greater or smaller according to whether we choose to imagine the masses of water to be disposed along the current path or across it. To take an extreme case, if the whole of the dormant water which was present in Test H could be spread over the surface of one electrode it would form a layer 1/122 cm. in

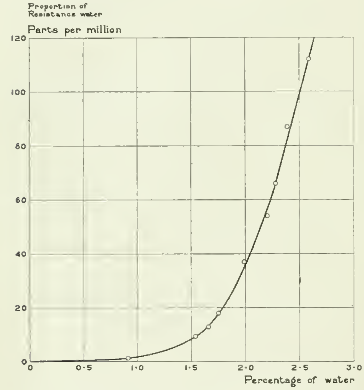

FIG. 26.—Proportion of *resistance water* to the total quantity of water in a pad of paper (see Table I).

thickness—about 3·2 mils. The resistance thread (which was about 1 in. long) would therefore be decreased in length by 3·2 mils, necessitating an equally insignificant decrease in its sectional area in order to maintain the observed resistance of 1,870 megohms. The dormant water would now be wholly in the current path in the form of a very thin sheet, but as its resistance would be much less than 1 ohm we may still regard all the water which is not in the resistance thread as dormant, in the sense that it does not form an appreciable part of the observed resistance.

Finally as regards evaporation: When water evaporates the electrolytic ions generally remain behind, and hence the number of ions in a unit volume of the remaining water increases and the specific resistance falls. But the volume of a conductor of given resistance is directly proportional to the specific resistance, and hence by neglecting the effect of evaporation the volume of resistance water has been again over-estimated.

Taking all these matters into consideration, the figures given in Table I seem rather more likely to be overestimates of volume than underestimates. At all events they may be accepted as of the right order of magnitude, and the significance of the experiment stands out clearly in spite of some unavoidable guesswork: A vast proportion of the whole volume of water in an absorbent insulator is dormant in the sense just defined. The resistance of the leakage paths through the insulator is determined by an exceedingly small fraction of the absorbed water.

The relation between the volume of resistance water and the total volume is shown as a curve in Fig. 26. The total volume of absorbed water in the paper is here reckoned as a percentage of the volume occupied by the pad of paper.

10. Dielectric Conduction in Dry Paper.

Incidentally the weighing experiment affords another example of the relative importance of moisture conduction and dielectric conduction. Referring once more to Table I, we see that when the absorbed water was reduced to a mere unweighable trace, the resistance of the pad of filter paper rose to nearly 12 million megohms, corresponding to a specific resistance of about 2,700 million megohms (cm. cube). This is far below the specific resistance of more thoroughly dried paper, which is certainly not less than 26,000 million megohms. The author is indebted to Mr. Welbourn for this figure; it is a value obtained by the British Insulated and Helsby Cables Company in their test room with carefully dried paper, but even in this case it is doubtful if every trace of water had been removed.

Accepting 26,000 million megohms as at all events a lower limit, it is evident that in Test I moisture conduction was at least 5,000 times greater than dielectric conduction, and in Test A when the pad of paper was much nearer a normal state as regards the quantity of absorbed water, moisture conduction outweighed dielectric conduction more than a million times.

11. The Law of the Moisture Curve.

The experiments on absorbent insulators suggest that underlying the phenomena there is some ascertainable law of conduction by moisture. The fact, which the wary reader will have perceived already, that it has been possible to compare one curve with another without taking potential *gradient* in the insulator into account, is sufficient proof that the curves have some simple property in common. And so they have; for in every case in which moisture conduction alone controls the resistance curve, it is found that over a considerable length along the curve the ratio R_v/R_{10v} is fairly constant whatever may be the value of v in volts. Hence although the insulators have varied widely in thickness, the ratio R_{50}/R_{500} has served quite well as a rough guide for comparing the different curves.

A good example of this property is afforded by the moisture curve for cotton given in Figs. 11 and 12. The fact that in this case a line drawn through the plotted observations forms a smooth curve over a very wide range of potential difference is of itself an indication that disturbances were absent, and hence we are justified in looking here, if anywhere, for a simple law. Table II gives

half a dozen ratios of R_v/R_{10v} read off from this curve, and considering the inevitable discrepancies due to instability the figures are remarkably constant and point to a definite law.

TABLE II.

Voltage Points for which Ratio is reckoned	Ratio $R_v : R_{10v}$
5 to 50	3·0
10 „ 100	3·1
20 „ 200	3·1
30 „ 300	2·9
40 „ 400	2·8
50 „ 500	2·8
Mean value of ratio R_v/R_{10v}	2·95

The law would be expressed empirically by the formula—

$$R = k \sqrt[x]{\frac{1}{v}};$$

and since in this particular curve the ratio R_v/R_{10v} is only a little less than $\sqrt{10}$, the exponent x must be a number not much greater than 2.

But Nature generally declines the Procrustean bed of formula. Just as in the case of fluid friction she has persistently declined to limit herself either to the first power or to the second power of the velocity (the only alternatives offered to her by the mathematical descendants of Procrustes), so here she refuses to abide by any one exponent. But in each particular case a value may be chosen for x which will express the law of the individual curve over a great part of its length, and hence when the ratio R_v/R_{10v} has been found by experiment, the formula may be applied to ascertain any other ratio R_v/R_{nv} for values of n lying between 1 and 10. Beyond this modest degree of practical utility the formula is only useful as an indication of the general character of the moisture curve. Further analysis of the characteristic curves may prove useful in suggesting causes for the wide variations from the ideal curve, but in the present stage it is safer to be guided by average results.

12. COMPOUND INSULATION.

If the examples which have come under review in the foregoing pages are divided into two groups according to whether the insulator was composed of absorbent materials alone, or on the other hand built up of some non-absorbent dielectric insulator in series with an absorbent insulator, then their characteristic curves will be found to exhibit a marked difference in curvature, the decrease in resistance being much larger in the first group than in the second. Figs. 2, 22, and 23, are examples of wholly absorbent insulation, and Figs. 3, 6, 20, and 25, all relate to what may be called compound insulation. In 47 curves obtained from insulation, composed entirely of absorbent materials, such as cotton, paper, cardboard, fibre, and other things, both varnished and unvarnished and including oil-impregnated paper, the average value of the ratio R_{50}/R_5 was 2·20.

This figure is confirmed by the results of a number of insulation tests on absorbent materials carried out by Mr. E. H. Rayner at the National Physical Laboratory.* The materials included presspahn, Manila paper, oiled paper, oiled board, oiled linen, Excelsior paper, Excelsior linen, and fibre, some of them being tested both in their ordinary condition and after varnishing. The insulators were tested under a compression of about 5·8 lb. per sq. in., and a reference to the compression-ratio curve in Fig. 16 shows that the ratio R_v/R_{10v} might be expected to be about 2·1. But as the resistance of each insulator was tested first at 200 and then at 1,000 volts, the value of R_v/R_{10v} may be more closely estimated from the observed value of R_{200}/R_{1000} by an application of the empirical formula. Mr. Rayner gives 17 tests within the range of measurement, and taking the whole of these the average ratio R_v/R_{5v} is 1·71. In arriving at this figure all the readings taken at 200 volts *after* the application of 1,000 volts have been excluded, as in nearly every case they showed a marked hysteresis effect. Now the formula shows that log (R_v/R_{10v}) will be equal to log 1·71/log 5, and hence we find that in Mr. Rayner's 17 tests the average value of the ratio R_v/R_{10v} was 2·15, compared with the author's figure of 2·20 deduced from 47 curves. The figure 2·2 may therefore be regarded as a good average value for the ratio R_v/R_{10v} for insulation which is wholly composed of absorbent materials, used under a moderate degree of compression.

But in the case of 12 curves obtained from compound insulation, that is to say insulation in which dielectrics like mica or ebonite were used in series with an absorbent material, the same ratio had an average value of a little less than 1·4. The difference is easily accounted for. The law of moisture conduction in any given absorbent material must be the same, whether there is a dielectric insulator in series with it or not, and assuming the dielectric has a constant resistance the absorbent insulator alone is responsible for the curvature of the resistance line. For an example turn to Fig. 6, which is the characteristic curve obtained from a supply meter in which the absorbent insulation of the windings is in series with the ebonite that serves to insulate the working parts from the case of the instrument. As it stands the ratio is only 1·35, but suppose we draw a new horizontal line at such a distance below the curve as will make the ratio R_{50}/R_{5} as deduced from measurements from this line to the curve, equal to the average for absorbent materials, namely 2·2. Then ordinates measured from the new datum up to the curve will represent the resistance of the absorbent insulation of the windings, and the distance from the new datum line down to the original base line will represent the resistance of the ebonite.† The height at which to

* *Journal I.E.E.*, vol. 34, p. 621, 1905.

† It may be the resistance of a conducting film on the surface of the ebonite, for external films have in several cases been found to follow Ohm's law. The point requires further investigation.

draw the new datum is easily found by trial and error, or it may be found at once from the following formula :—

$$\text{Constant part of resistance} = (\text{total resistance at 500 volts}) \frac{a - n}{a - 1}$$

where n is the observed value of the ratio R_{50}/R_{500} and a is the value of this ratio for the absorbent insulator by itself. In the present example the observed resistance at 500 volts was 1,140 megohms, n was 1·35, and we may take for a the average value 2·20. With these figures the resistance of the ebonite alone is found to be 810 megohms, and a datum line has been drawn in Fig. 6 to represent this value. The only uncertainty here lies in the value we choose for a, the ratio for the absorbent part of the insulation. Now although we have seen how mechanical pressure on the absorbent material may cause this ratio to vary from about 1·7 up to as much as 4·3, yet such wide variations have not been found to occur in practice. Probably absorbent materials are always used under compression, but however that may be, the ratio for absorbent insulators under the ordinary conditions of use does not seem to exceed 2·6, and it is frequently as low as 1·8. If these extreme figures are substituted for 2·2 in the above calculation the resulting values for the resistance of the ebonite will be 890 and 640 megohms respectively, instead of 810 megohms. Such variations as these do not in any way affect the utility of this method by which the two components of an insulation may be separately estimated. In general, if the curve of a compound insulation of the kind we are considering shows a ratio as high as 2 we may be sure that the resistance of the dielectric component has fallen to something approaching zero, either because it has broken down in itself, or because it has been shunted by some kind of absorbent dirt. An example of this happens to be available in Fig. 5. This curve was obtained from an ammeter having absorbent insulation in series with ebonite, yet the ratio is nearly 2 and the resistance is much below the normal value for insulation of the kind.

Upon removing the cover of the instrument the ebonite was found smothered in a mass of fibrous dirt which in the course of a dozen years or so had found its way there through a small hole in the case. Upon removing this highly absorbent shunt and cleaning the ebonite the resistance rose to over one million megohms.

It must be remembered that a non-absorbent dielectric in series is not the only cause of a low ratio value. We have already seen in Fig. 17 how the curve flattens out when there is enough absorbed water to form paths of constant resistance in parallel with those which give a typical moisture curve. But under such circumstances the resistance curve will be so very far below the average level which it occupies under more normal conditions that there is no likelihood of the low ratio that is associated with wet insulation being attributed to the presence of a non-absorbent dielectric in series with the absorbent materials.

The percentage degree of absorption at which leakage paths of constant resistance begin to form inside a porous insulator must naturally vary widely in different cases. Judging from the shape of the curves obtained from paper it would appear that so long as the absorbed water does not exceed the amount which is naturally absorbed from the air, leakage through paths of variable resistance is paramount and the normal moisture curve will be obtained. How far paper is typical of absorbent insulators in general remains to be seen.

The experiment of weighing the water has already shown us how small a proportion of the absorbed water is actually utilized in forming the leakage paths which determine the resistance of an absorbent insulator. Referring once more to Table I, we see that under quite ordinary conditions the dormant water may easily outweigh the resistance water by at least 10,000 to 1. The exact proportion is of little importance, but when once the principle governing the disposition of absorbed water inside a porous insulator has been grasped, the confusing phenomena of leakage through moisture begin to arrange themselves in some sort of order.

13. Electric Endosmose in a Model Insulator.

So far the investigation had not suggested any rational explanation of the moisture curve ; possibly because the importance of the principle just referred to was not recognized until after the model insulator, which is now to be described, had given a visible demonstration of the cause of the gradual decrease in resistance with increasing potential difference. The explanation given in the following pages was ultimately arrived at, not as the result of previous experiment, but by first considering what was likely to happen when atmospheric moisture condensed inside a porous insulator, and then putting the notion to the test of experiment.

When condensation takes place on the surface of a solid body it first makes its appearance to us in small detached drops clinging to every roughness, every scratch on the surface. If we suppose the solid body to be an insulator of infinite (or at all events immeasurable) resistance, the presence of detached drops of water will not make any appreciable change in that resistance, and the same holds good for the maze of internal surfaces inside a porous insulator when moisture condenses there. But, as we have seen, the absorption of a mere trace of water brings about a vast decrease in resistance ; reduces it from an immeasurable value to one easily within the range of our instruments. We cannot suppose the drops to coalesce in order to form a continuous leakage path, because in that case conduction would be simply that of an electrolyte and would follow Ohm's law, leaving the moisture curve unexplained. We must therefore look for connecting links between the drops to establish a complete conducting chain. It would be natural to suppose the links to be films of some kind condensed on the surfaces of the capillary passages in the insulator, and to account for the characteristic curve the films would have to be endowed with a property analogous to that of the electric arc ; with increasing electric pressure they must increase their sectional area either by reason of the leakage current they carry, or in consequence of some effect which, like endosmose, depends on the potential gradient. At the time this hypothesis was first outlined it hardly appeared any more likely to contain the germ of truth than half a dozen others that had suggested themselves in the course of research, only to break down on trial. Nevertheless it was put to the test of experiment, and has proved itself capable of accounting for the facts.

To experiment with a series of drops and connecting films deposited on any kind of exposed surface would have

led to almost certain failure, owing to the difficulty of protecting the films against currents of air. This liability is almost non-existent inside a porous insulator, where any considerable change in the humidity of the air occupies a comparatively long time, and the consequent changes in the films and their resistance are not too quick for experiment. To imitate this condition of moderate stability it was decided to construct a model insulator by drawing a series of drops of water and bubbles of air into a capillary glass tube, so that each bubble should constitute an enclosed region within which a film could form on the internal surface of the tube and remain there entirely undisturbed by air currents. Glass was not only an obvi-

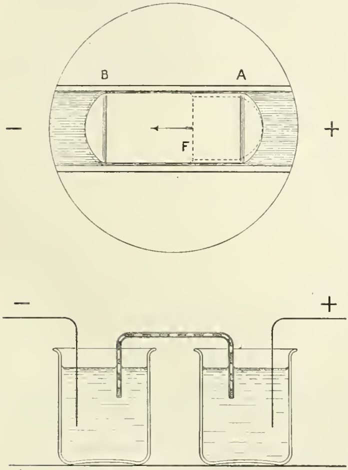

FIG. 27.—Elementary Model of an absorbent insulator. The upper figure represents one of the air bubbles as seen in the field of a microscope.

ously convenient insulating material for the purpose, but as it was intended to look for some visible effect of endosmose a transparent tube was essential.

The glass tube, which was about a couple of inches in length with a bore of 12 or 14 mils, had its ends bent downwards so as to dip into water contained in two small beakers. Before placing the tube in position it was completely filled with a succession of drops of water separated by bubbles of air, the bubbles having an average length equal to four or five times the bore of the tube. Two copper wires, one in each beaker, served as the electrodes. The complete arrangement, as shown in Fig. 27, was fixed under a microscope in such a position that portions of two adjacent drops, with the whole of the air bubble in between them, came within the field of view, as indicated in the upper part of the same figure. At A and B dark transverse lines, corresponding to "Newton's rings," were seen at the end of each drop where the water-air surface approaches the glass at a capillary angle. These lines formed convenient gauges for estimating the initial thickness of the film of water deposited on the glass, and it was apparent that in the neighbourhood of the capillary edges of the drops the thickness of the film did not exceed one-quarter of the mean wave-length of light.

To understand the behaviour of this tube it is necessary to have the principle of electric endosmose clearly in mind, and as this effect is almost inseparable from electricity and water a short account of it may not be out of place in a paper which is so largely concerned with the passage of a leakage current through moisture.

To begin at the beginning. When an electrically-charged body is placed in an electric field it is attracted one way or the other according to whether the charge it holds is positive or negative, the attractive force being proportional to the potential gradient (volts per centimetre). It does not matter what the attracted body is made of; water will do as well as anything else, and, given the proper conditions as regards voltage gradient and so on, it will move. For instance, water which is lying on an insulator in an electric field will be urged towards the negative side of the field and will flow in that direction if it is free to do so. A little scrap of paper jumping up from the table towards an electrified stick of sealing-wax is a more familiar example of the same action. The electrification of the sealing-wax provides the potential gradient, and the scrap of paper moves upwards if the gradient is steep enough.* Both the scrap of paper and the water move for the same reason, and the only difference lies in the mode by which they receive the necessary charge of electricity. In the case of the scrap of paper the charge is induced by the sealing-wax; whereas the water becomes charged by *contact* with the insulator, just as zinc becomes charged by contact with copper. But although no real difference in principle is involved the action goes by very different names in the two cases. When the scrap of paper jumps we are content to say that it does so because it is attracted, whereas when the water moves because it is similarly attracted the action is called endosmose.

Any liquid would exhibit the phenomena of electric endosmose provided two essential conditions were fulfilled. These are that the liquid must be either electropositive or negative to the channel which contains it, otherwise there will be no charge and no force; and its specific resistance must be very high, otherwise it will be impossible to maintain a steep potential gradient inside the liquid without overheating by excessive current. Let an attempt be made to propel mercury by endosmose, and a gradient of something like 50 volts per centimetre would be required to overcome friction. But by the time the gradient had reached 2 or 3 volts per centimetre the resulting current flowing in the mercury would have raised it to boiling-point and the experiment could not go on.

Water, and especially pure distilled water (or condensed

* Thales (500 B.C.), to whom we are indebted for the sealing-wax experiment, does not seem to have laid any particular stress on potential gradient as an essential factor.

water), happens to possess both the essential properties in a remarkable degree. It is strongly electro-positive to all insulators (with the one doubtful exception of hair); and its resistance is from 20 million to 2,000 million times greater than that of mercury, so that it is possible to maintain a potential gradient of several hundred volts per centimetre without any overheating by electric current.

Endosmose may be made visible in a short glass tube connecting two water vessels. By contact with the glass the water in the tube acquires a positive charge which occupies a cylindrical layer of water next the wall of the tube, being held there by the corresponding negative charge in the glass surface. When a potential difference of several hundred volts is maintained between the water vessels, the charged water in the tube is strongly attracted towards the negative vessel and moves in that direction down the potential gradient. This movement is confined to the charged layer and such water as it can drag along with it, and when the bore does not much exceed half a millimetre the whole of the water will be set in motion and may be seen travelling slowly towards the negative end of the tube.

Endosmose has been chiefly studied as it appears in glass tubes and in the capillary passages inside porous materials; hence the name, which may be clumsily translated "within-propulsion." But the name must not mislead us. It is not essential to have the water *within* anything; all that is necessary is that the water should be lying in contact with an insulator and forming a conducting path between two electrodes. Then, if the voltage gradient between the electrodes is steep enough, and the water is free to move, it will find its way towards the negative electrode whether there is any definite channel for it to run in or not. But without some kind of trough or tube the water is apt to go by all sorts of devious ways towards its goal, and the confused motion becomes difficult to follow by eye.

To return to the experimental tube with its chain of drops and films. On applying an electromotive force to the electrodes in the two beakers the effect of electric propulsion or endosmose was at once apparent. On closing the circuit the surfaces of the two drops visible in the field of the microscope instantly changed their curvature, the positive surface A pushing its edge out towards the negative side of the field of view, and the negative surface B decreasing its curvative by withdrawing its edge inwards. The dotted lines in Fig. 27 indicate the general nature of this effect, but grossly exaggerate the extent of the change. If the film connecting the two drops happens to be visible* every part of it is seen to experience a sudden force pushing it towards the negative side. The effect of the hydraulic pressure produced in the drops by the electric propulsion is seen at the same time; a stream of water is forced out from the edge of the positive drop and flows rapidly towards the negative drop, increasing the thickness of the film as it goes along. The advancing wave front (F in Fig. 27) of the travelling water is clearly visible, and if the potential difference is gradually increased, the growing thickness of the now moving film is made apparent by its assuming, one after another, the colours characteristic of thin films.

* The film is only visible when parts of it are thick enough to give some of the colours of Newton's rings. If its thickness is much less than a quarter of a wave-length the film cannot be seen.

The sectional area of the films is of course exceedingly small compared with that of the drops and hence the resistance of a complete tube of given diameter is determined almost entirely by the aggregate length and mean thickness of the films, the resistance of the drops being negligible by comparison. The visible increase in the thickness of the film will therefore be made evident also by a concurrent fall in the resistance of the tube, and if a series of tests be made at gradually increasing potential differences the characteristic curve of the tube as an absorbent insulator may be drawn. In Fig. 28 a curve of this kind has been plotted from tests made on a glass tube about 1·5 in. long and 13·5 mils bore, containing water separated by 12 bubbles of air, each of which provided a film length of about 70 mils. The early part of the curve is smooth enough, but the current became increasingly unsteady as the voltage was increased and accurate observation was impossible at the higher readings.

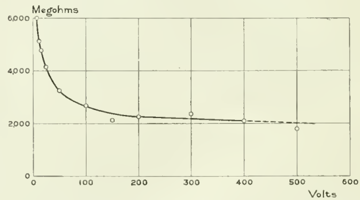

FIG. 28.—Characteristic curve obtained from a capillary glass tube filled with drops of water and bubbles of air, and arranged as shown in Fig. 27.

When the electromotive force is cut off, the surfaces of the drops are instantaneously restored to their normal shape. The surplus water in the films then withdraws very slowly into the adjacent drops, until, after a period which may be hours rather than minutes, the films are reduced to their initial thickness and the resistance of the tube recovers its initial value. The extreme slowness both of the initial formation of the films and their recovery after the application of any considerable potential difference, was not fully realized until the results of all the tests made on tubes were collated some time after the conclusion of the experiments. It then became apparent that the majority of the tests made with single tubes had been carried out before the films had settled down into a normal condition, and their instability naturally led to large discrepancies, particularly at the higher voltages.

But a single tube, one capillary channel, could hardly be expected to give a faithful imitation of a real insulator. Much better results have been obtained from models composed of a number of similar tubes connected in parallel, particularly when they have been given ample time to settle down into a normal condition. The three curves in Fig. 29 were obtained from a model made up of 13 tubes in parallel, curve A being taken 20 hours after filling the tubes, and curves B and C at 44 and 98 hours respectively. In these tests leakage along the external surfaces of the

tubes was eliminated by guarding each tube, and in order to ascertain whether the guard wires upset the uniformity of the potential gradient, a fourth curve D was taken at 113 hours with the guard wires removed. This curve so closely follows curve C that to avoid confusion the mean values of the observations in the two tests have been plotted in Fig. 29 as a single curve representing both C and D.

Reckoning from the average of these four curves the ratio R_{50}/R_{500} is 2·1, a figure which agrees surprisingly well with the average ratio 2·2 obtained from absorbent insulators.

Hysteresis, which is such a marked feature of the moisture curves of real insulators, is equally characteristic of the model. In each series of tests upon the model the return curve obtained by retracing the voltage steps from

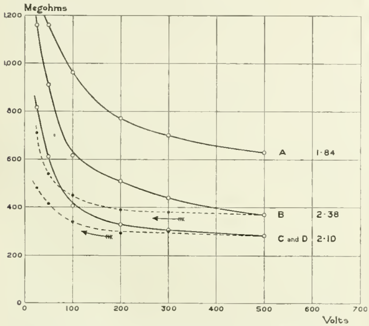

FIG. 29.—Characteristic curves obtained from a Model Insulator composed of 13 capillary glass tubes arranged in parallel.

A 20 hours after filling the tubes.
B 44 ,, ,, ,, ,,
{C 98 ,, ,, ,, ,,
{D 113 ,, ,, ,, ,,

500 back to 25 volts has indicated a pronounced hysteresis effect. The return curves obtained immediately after curves B, C, and D, have been included in Fig. 29, and should be compared with the examples of hysteresis in real insulators which have been given in Figs. 2 and 5.

The general resemblance of the curves given by glass models to those which are characteristic of absorbent insulators is evident. In the decreasing resistance with increasing voltage, in the extent of the decrease, in the slow recovery or hysteresis, even in instability, the films and drops possess properties which are common to every absorbent insulator. The dormant water which we found in the pad of paper is here in the drops, and the resistance water is visible in the films which link the drops together into a conducting chain, and provide the high resistance.

But in one matter a simple model composed entirely of open tubes differs fundamentally from a porous insulator. The first effect of heating an absorbent insulator is to bring about a very large decrease in resistance. Heat this too simple model, and the expanding air bubbles lengthen the films and increase the resistance.

But, after all, the structure of the model is not much like the real thing. For the tangled maze of interconnected channels in a porous insulator the model substitutes a number of parallel channels, each going without a break from one electrode to the other; it contains no blind alleys and no cross-connections. Hence in the model the proportion of dormant water falls far below the proportion which we have found by weighing the water in the real insulator. How far below can only be estimated when the thickness of the films is known.

14. Thickness of the Films.

The net resistance of a measured length of film in a glass tube containing drops of water of known conductivity enables the thickness of film to be estimated, on the assumption that it is uniform. Reckoned in this way the films in the tube which gave the curve shown in Fig. 28 had a thickness not exceeding 10 millionths of an inch. The films are of course very far from being uniform in thickness and hence this figure is only a rough estimate.

One of the films in the same tube was measured by the method of Newton's rings, which gave the value 5·5 millionths of an inch.

The two measurements were made at the same time, the films having the maximum thickness corresponding to a potential difference of 500 volts. The two values do not differ more than one would expect, and as the second method is the more accurate we may say that in this tube the thickness of the films was about 6 millionths of an inch when swollen by the action of endosmose. Hence judging by the concurrent decrease of resistance, their initial thickness must have been about 2 millionths of an inch. This is so much less than one-quarter of a wave-length of light that in the initial state the film had no perceptible colour by which to estimate thickness.*

15. Dormant Water in the Model.

We can now estimate the proportion of dormant water to film water in the model. Most of the tubes have been about 2 in. in length, and about half the length has been occupied by films and the other half by water. The bore of the tube being about 14 mils, its perimeter is 44 mils. The initial thickness of the film was $2/10^6$ in. $= 2/1{,}000$ of a mil, and the aggregate length of film was about 1,000 mils. Hence the volume of water in the films was about 88 cubic mils.

The sectional area of the drops is 154 sq. mils, and since they occupied about half the length of the tube their aggregate volume was about 154,000 cubic mils. Hence the ratio of dormant water to film water was $154{,}000/88 = 1{,}750$. That is to say for one part of water in the films there are something less than 2,000 parts of dormant water.

Now in a real insulator the corresponding proportion is, as we have seen, much more like 10,000 or even 100,000 to 1; from 5 to 50 times as much. To represent reality in this respect it would be necessary to build up a model with

* The wave-length at the sodium line in the spectrum is 23 millionths of an inch. It is worth noting that at its thinnest the film has depth for about 170 molecules.

a very large number of closed tubes in addition to the open or conducting tubes, and to interconnect the two sets, by numbers of cross tubes. When the whole assemblage was filled with water and air it would form one hydraulic system, although electric conduction would still be confined to the open tubes. The whole of the water, both in the open and in the closed tubes, would be attracted towards the negative electrodes, and at every place where there happened to be a convenient junction between a closed tube and an open one, dormant water might be driven out into the latter and assist in swelling the films in the conducting channels.

16. The Properties of a Model Insulator.

Heat this complex model and the expansion of the trapped air* in the closed tubes will drive a large volume of dormant water into the conducting channels. At the same time the expansion of the air in the open tubes may have lengthened or even broken up some of the films, but remembering that the closed tubes may contain perhaps fifty times the volume of air and water, it is evident that the quantity of dormant water forced out from the blind alleys will be enough to flood the conducting channels, quite apart from what may happen to individual films. The flooding of the conducting paths naturally brings about an enormous fall in resistance. Lower the temperature and the air bubbles throughout the system will contract and the flood water will retire into the blind alleys The films then slowly recover their initial thickness as the surplus water is forced out of them by the tension of the water-air surface, and the resistance rises to its former value.†

Another remarkable property of absorbent insulation finds a ready explanation in the model with its tubes full of drops and films. Over and over again in the course of the investigation a number of moisture curves have been obtained under widely different conditions as regards the quantity of absorbed water. Yet the curvature of the characteristic has remained practically unchanged throughout the whole series of tests notwithstanding the enormous changes in the general level of resistance which accompany changes in the amount of absorbed moisture. This permanence in the shape of the curve has already been referred to, and in view of what has been demonstrated by means of a bundle of capillary glass tubes the explanation is clear. Place a damp insulator in a dry atmosphere so that evaporation takes place. Evidently the more accessible films will evaporate first, followed by film after film, and the least accessible and thickest films will be the last to go. But as each film gives more or less the same sort of curve, the curve from a few dozen film channels in parallel would be indistinguishable in shape from the curve obtained when there were hundreds or thousands of films acting as parallel leakage paths. Hence so long as a few film channels are left intact—just enough to carry a measurable leakage current—the resistance-voltage curve will retain its characteristic shape. We now realize why it was that a piece of impregnated paper cable which had absorbed a trace of water, giving a resistance of several hundred thousand megohms, had a characteristic curve of the same shape as that obtained from a dynamo armature the resistance of which was less than a dozen megohms. The curve is characteristic of the film with its adjacent reservoirs of dormant water; the magnitude of the conductance is simply a question of the number of film paths acting in parallel.

The marvellous rapidity with which the resistance alters when a change occurs in the humidity of the air is of course attributable to the extreme tenuity of the films.

All these phenomena should become visible in a complex glass model if only we had skill to make it. But, after all, the necessary complexity is available in every porous insulator, for there we have a tangled system of innumerable conducting channels, cross connections, and blind alleys, ready made; an elaborate natural system which could not be imitated by any artificial arrangement of a few glass tubes. If we direct our mental vision to the inside of a real absorbent insulator we shall see a bewildering number of channels occupied by films and drops in which the same kind of actions are going on as those which are visible in the glass tube; and mingled with the elaborate hydraulic system there will be a quantity of air, some of it—perhaps a large proportion of it—trapped in blind alleys by plugs of dormant water, and always ready to expand when heated and drive the water out into the conducting channels.

17. Summary and Conclusion.

This vision of what goes on inside an absorbent insulator, misty and imperfect as it is, provides an explanation in general agreement with the facts. In putting it forward the author is conscious of difficulties and obscurities which leave the mind doubtful, but the doubts are just those which come from ignorance of the precise structure of absorbent bodies and the mode in which they harbour moisture. In all probability the microscope would dispel a good deal of this cloud of ignorance if it were applied to some typical material like a thread of cotton.

But the facts which have emerged from the investigation leave no room for doubt as regards the main characteristics of insulation resistance under working conditions.

The true dielectric resistance of insulation is enormous compared with the actual insulation resistance obtained in practice, and in all ordinary cases we need only consider the leakage which takes place through films of moisture condensed on the external and internal surfaces of the insulating material. Dielectric leakage is insignificant and may be left out of account.

The quantity of water in the conducting films of moisture is not only very small, but it forms an exceedingly small proportion of the whole volume of absorbed water.

Impregnating an absorbent insulator with oil or varnish delays the absorption of water and no doubt limits the amount absorbed, but it does not prevent the ultimate formation of the moisture films which constitute leakage paths.

Conduction through absorbent insulation does not follow Ohm's law. The relation between the resistance of an absorbent insulator and the potential difference which is

* Inside a porous insulator containing a normal amount of moisture the volume of air will vastly exceed the volume of dormant water, and there must be innumerable bubbles of air trapped inside capillary spaces by drops of water.

† The above explanation of the action of heat on absorbent insulation has its origin in a suggestion made by Mr. A. Campbell and embodied by Mr. E. H. Rayner in the report on Temperature Experiments at the National Physical Laboratory (*Journal I.E.E.*, vol. 34, p. 624, 1905).

applied to it is expressed by a curve which is characteristic of conduction by films and drops.

When the absorbed water exceeds the amount which the material can hold in the form of dormant water and leakage films it begins to form conducting paths of constant resistance. Hence the moisture curve gradually decreases in curvature as absorption goes on, and ultimately when the resistance has fallen to a very low value the curve is reduced to a horizontal straight line, indicating conduction by Ohm's law.

In compound insulation consisting of an insulator in which conduction follows Ohm's law, in series with an absorbent material which follows the law of moisture conduction, the resultant curve has less than the normal curvature.

The degree of curvature in the characteristic curve of compound insulation enables the resistances of the two components to be separately estimated.

In compound insulation a curve of normal curvature indicates failure of the dielectric component. A straight horizontal "curve" (Ohm's law) indicates failure of the absorbent component.

Finally, the broad principle of film conduction in an absorbent insulator is clear ; the moisture curve—the first part of the complete characteristic curve—is the direct result of electric endosmose. The electrically produced hydraulic pressure drives dormant water into the films, and their increasing thickness is made evident by the gradual fall in resistance as the potential difference is increased.

At what point leakage through moisture becomes dangerous ; whether the ultimate effect of prolonged endosmosis is to safeguard the insulation by driving all the water away from the positive conductor in a continuous-current system, and from both conductors if the supply is by alternating current ; whether it is possible to predict the breakdown voltage—these and other questions can only be answered by an investigation of the second part of the characteristic curve. Preparations for this are not yet complete, and so far it has only been possible to extend the curve to the breakdown point in one or two simple cases for which the voltage already available proved sufficient. In these examples the curve began to bend downwards at pressures well below the breakdown value, thus indicating the impending failure without exposing the insulation to the risk of permanent injury. It remains to be seen whether this useful effect is general, or whether, as seems more probable, it is confined to insulating materials in which failure begins along already existing leakage channels. It is a significant fact that in the model insulator breakdown begins in the form of sparking along the films from one drop to another. Questions of this kind go to the very root of the matter. It is customary to account for breakdown by dielectric stress ; a blackened hole appears in the insulation and the inference is too hastily drawn that the puncture process was instantaneous and could not have been foreseen by any kind of test. But nothing in Nature, not even an explosion, takes place instantaneously, and the breakdown of an insulator is only sudden to the mind that does not apprehend it.

The time may never come when it is possible, by systematic insulation testing, to forestall breakdown by diagnosis of the disease and removal of the cause. To-day the problem as a whole looks wellnigh insoluble, and with no visible goal ahead of us we must be content to gain a clearer insight as we go along in more or less the right direction. That road is always open to us and the author hopes that facts recorded in this paper may serve as stepping-stones on the way.

Note.—The whole of the experimental work has been carried out at Acton-lane works by Mr. S. F. W. Finnis, to whom the author is greatly indebted for the skill and patience with which the laborious and in many cases difficult experiments were conducted. Not the least among many difficulties was the necessity for carrying on the investigation without interrupting the ordinary work of the Experimental Department of which Mr. Finnis has charge. The author also wishes to thank Mr. B. Welbourn of the British Insulated and Helsby Cables Company for his kindness in providing samples of paper cables and the oil and paper used in their manufacture, together with data relating to the specific resistance of these materials. It is always a pleasant task to make acknowledgment of the help which is so freely given by one member of the Institution to another.

APPENDIX.

Insulation Valves.

The effect which polarity has on the resistance of some kinds of insulation has been known from the early days of telegraphy in connection with overhead wires run on earthenware insulators. The same effect is frequently met with in testing the insulation resistance of electric-light wiring. So far as the author is aware it was first traced to porcelain insulators by Mr. Bernard Holt. Writing from Perth, West Australia, to the author's firm, Mr. Holt has described some remarkable instances of valve action which he has come across. A new installation of interior wiring, when tested from one wire to the other with the switches open, gave 1·5 megohms with the testing voltage in one direction and 9 megohms when the polarity was reversed. Another installation gave a similar result and, by elimination, Mr. Holt traced the effect to the switches. One of these when removed from this installation and tested for insulation resistance from one terminal to the other, differed in resistance by several hundreds per cent according to the polarity of the terminals. The switch was of the ordinary tumbler pattern mounted on a china base.

The author has had no difficulty in verifying Mr. Holt's tests in every particular. House wiring, whether tested from wire to wire with the switches open, or from the wires to earth, often shows a valve effect. Porcelain base switches of inferior quality have invariably acted like valves. On the other hand, switches of the best quality in which well glazed china is used gave resistances from about 100 megohms up to several thousand megohms, and it was only when the resistance was well within the range of the ohmmeter used for these tests that a valve action could be detected. It is probably inherent in every earthenware insulator. A number of switches of good quality were found to give 10 megohms or so with the voltage applied in one direction, and over 100 megohms

when the testing leads were reversed, the rise in resistance being practically instantaneous. Apart from the highly insulating glaze, earthenware is something between a rather good conductor and a very poor insulator, but it need hardly be pointed out that if a switch base were covered in every part, including all screw holes, with a good glaze which was entirely free from cracks, the resistance between terminals or from terminals to earth would amount to several thousands or even millions of megohms. Such high values would indicate a needless perfection and are no doubt unattainable in practice, but when we find many china bases of poor quality giving not more than one or two megohms each, even in dry weather, we naturally begin to inquire why some limit should not be set to the discontinuity of the glaze. A resistance of two or three hundred megohms would at least be an indication that the glaze was well applied and reasonably free from cracks.

To ascertain the cause of the valve action, tests were made on a flat block of porcelain of good quality. The resistance being far too great for easy measurement, the glaze was partially removed by grinding in order to approach the condition of an ordinary switch base and at the same time obtain a smooth flat surface. Three small electrodes, A, B, and T (see Fig. 30), were secured to

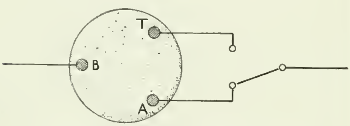

FIG. 30.—Glazed Porcelain Block fitted with three electrodes for investigating the polarity or "valve" effect.

the surface, and the method of experiment was to measure the resistance of the path A B and compare it with that of the path T B, the region round B being common to both paths. Current was never allowed to traverse the path T B for more than two or three seconds at a time—just long enough to allow the ohmmeter reading to be noted—and hence any substantial increase which might be observed in the resistance of this path would be confined to the neighbourhood round electrode B and would be the result of current flowing in the path A B. It was found that when current, flowing in either direction, traversed the path A B the resistance of this path gradually rose until by the time the current had been flowing for half an hour or so the resistance would be twenty or thirty times the initial value. By cutting off the current in A B and immediately taking the resistance of the reference path T B, it was at once seen whether the increase in A B had taken place at electrode B or not. In this way it was proved that when electrode B was positive, practically all the increase in the resistance of A B occurred at or near B; and when that electrode was negative then no material change took place there. That is to say the increase in resistance that results from the leakage current is almost entirely confined to the region round the positive electrode, the conductor where the current enters the earthenware. In one experiment the initial resistance of the path A B was 40 megohms, and on switching on the testing current, which in this instance entered the porcelain at A, the resistance rose to several thousand megohms in the course of two or three minutes. During this time the reference path T B changed from an initial value of 8·0 megohms to a final value of 8·2 megohms. Hence of the enormous increase in the resistance of A B only 0·2 megohm occurred in the region near the negative electrode B; practically the whole increase took place in the region of the positive electrode A.

By making both the electrodes very small, the resistance-change may be made to take place almost instantaneously, no matter which way the current flows. If one electrode has a smaller area than the other then the change will take place more quickly when the current enters the china at the small electrode than it does with the current going the other way. By using one very small electrode and one of fair size, the increase is easily made to occur so quickly when the small electrode is positive that it will appear to take place instantaneously, whereas when the electrode of large area is positive the change may take place so slowly that no material alteration will be detected in the time occupied by an ordinary insulation-test. The word "area" is used here in rather extended sense, for it is clear that a metal piece having a large area in contact with the glazed surface might act as an electrode of small area if there happened to be only a few small cracks in the glaze available for the passage of current from the metal into the body of the earthenware. In this connection it would be more precise to refer to access to the interior of the insulator than to area, although the two sometimes mean the same thing.

Access-area is frequently the result of accidental circumstances. The screw holes in a porcelain base are often insufficiently glazed, and hence the fixing screws for the terminal pieces are apt to have rather easy access to the conducting earthenware beneath the glaze. It is a matter of chance which of two screws will have the better access, and although any individual switch may show a marked valve effect simply because one terminal has a better access than the other, yet a complete installation of similar switches may show no such effect, because they are coupled up to the wiring without any regard to valve direction, and the installation could only show a polarity effect if there chanced to be more valves opening one way than the other.

But chance is not always the governing factor. Where there is some systematic difference in access-area, arising out of constructional features and accompanied by a systematic coupling to a circuit, there the circuit as a whole will show the valve effect. An overhead telegraph line is a good example. At every insulator the line wire, and its binding on the well-glazed surface of the insulator, has a far smaller access-area than the fixing bolt embedded inside the earthenware. Such a line will have a higher insulation resistance to earth when the line is made positive than it has when the polarity is reversed. Electric wiring when tested from circuit to earth will show the valve effect for much the same reason.

The increase in resistance at the positive electrode seems to be due to the clogging of the leakage channels, both the cracks in the glaze and the capillary passages in the body of the earthenware, by the products of electrolysis. But

it is significant that the valve effect is almost as great when platinum electrodes are substituted for the usual brass pieces. In this case oxygen alone is produced at the positive electrode, but some chemical change evidently takes place in the region near the electrode because even with platinum the earthenware is observed to become discoloured, and the resistance remains at the increased value for 24 hours or more after cutting off the leakage current. This seems to point to some solid non-conducting substance choking the pores of the insulator. The action of endosmose in driving moisture from the positive towards the negative electrode must not be overlooked. If in this way the water were driven out of the cracks in the glaze near the positive electrode, a very large increase in resistance might easily take place. But upon the whole the facts point to clogging by the chemical action accompanying electrolysis, although endosmose may play a subordinate part.

An installation of wiring, which when new may have no valve action when tested from wire to wire, will soon acquire it if the supply is by continuous current. In this case the positive side of every porcelain switch base becomes so clogged by the prolonged electrolysis which goes on whenever the switch is open, that a systematic difference in access-area comes about, the positive terminals in contact with the clogged earthenware acting as the electrodes of small access-area.

The insulation valve is thus seen to be closely related to other well-known electrical valves which depend for their action on the two electrodes having widely different freedom of access to an electrolyte. Glazed earthenware seems peculiarly well adapted to produce a valve effect, but no doubt other porous insulators may be found to act in the same way.

As to the question whether the normal resistance or the abnormal is to be taken as correct, the answer must be that both are real, both are effective in preventing leakage. In a continuous current system the higher value is the one which actually governs leakage if the polarity of the system remains unchanged. But in telegraphy this is not always the case, and it is no doubt advisable to carry out insulation tests on overhead lines with the line wire negative and use the lower resistance value, so obtained, in estimating the signalling capacity of the circuit.

NOTE.—In introducing the paper the author gave an experimental demonstration of the moisture effect by means of a mirror ohmmeter having a scale 30 feet in length and easily visible to a large audience. Measurements of insulation resistance were made at a series of ascending voltage of (1) a dynamo, (2) a varnished winding, (3) the skin of the hand, and (4) a model insulator composed of a bundle of capillary glass tubes filled with water

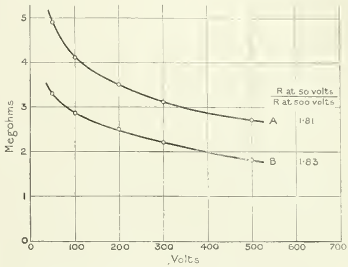

FIG. 31.—Moisture Curves plotted from readings taken in the course of the experimental demonstration at The Institution of Electrical Engineers, on 27th November, 1913.

Curve A: Insulation Resistance of a Dynamo, lent for the experiment by Mr. W. Clark.
Curve B: Resistance of a Model Insulator prepared by Mr. Littlejohn, composed of a bundle of capillary glass tubes.

and bubbles of air. Two moisture curves plotted from the readings so obtained are given in Fig. 31. The readings were noted by Mr. E. B. Vignoles.

DISCUSSION BEFORE THE INSTITUTION ON 27TH NOVEMBER, 1913.

Professor Silvanus Thompson.

Professor SILVANUS P. THOMPSON: I think that Mr. Evershed's paper will be, at any rate for some years to come—if not for more than some years—a standard of reference, and we shall look back upon it as a very definite and notable contribution to our knowledge of a very ill-explored but important branch of our science. We have known all too little about the conductance of insulators, and I think we shall be particularly indebted to Mr. Evershed for having directed our attention to what is very rightly called the characteristic curve of insulation resistance. It may be that we shall not always express ourselves in the same terms; it may be that we shall perhaps not always take exactly the ratio of the apparent resistance at 500 volts and at 50 volts; but at any rate, whatever we do in the future, we have now a datum to start from. Mr. Evershed suggests the measured resistances at 50 volts and 500 volts as furnishing a pair of points of reference, with a curve joining them which we can compare as between one substance and another to see whether they behave alike in their conducting properties; and for that definition, if for nothing else, I think this paper is valuable. It will be our own fault if, having now the means of measuring the insulation resistance in other cases and with other materials, we do not choose to follow the lead that Mr. Evershed has given us, and produce characteristic curves which shall be comparable, in the way in which they are made and plotted, with his. He has laid the foundation, therefore, for a certain definite advance in our knowledge and our means of expressing our knowledge on this subject. When I have said that, I have not said what is perhaps even a greater matter for those of us who have listened to Mr. Evershed; again and again throughout his paper he has given us excellent suggestions, hints, and points to excite our curiosity and our imagination as to what it is that is going on—as to what are the physics of this particular process of the leakage of electricity through the substances which are commonly called insulators. We must all have been impressed, for example,

Professor Silvanus Thompson.

with that exceedingly beautiful arrangement of films of water in capillary tubes to imitate by known appliances the behaviour of the water in the pores of solids. When he asked us to think of these porous channels ramifying about in all manner of tortuous directions, having blind ends and holding dormant water which could not take any part in the conductance because it led nowhere, when he gave us this *aperçu*—this vision, as it were—of the interior of a solid, surely we carry away with us a picture in our minds which we can fill up at leisure as more knowledge comes, and we shall be better able to grasp what is going on in materials when we make measurements in the laboratory or in the workshop.

One of the most important points comes out strongly; that is, how very little of the water that is absorbed by an insulator takes any part in the operation. Although it may be that only one-millionth part of the whole of the water is really conducting the leakage current through it —and how difficult it is to stop that millionth!—is it not a most remarkable fact that no chemical substance has yet been found with which to impregnate paper or any of those cellulose materials so as effectively to stop those minute channels? We may parchmentize the material and get rid of its fibre; we may what is termed vulcanize it; we may impregnate with vitriols, oils, fats, and all manner of varnishes, etc.; but we are continually eluded by the water which for ever manages to permeate through the cellulose material. It may be that some day a chemical discovery will be made which will enable us to impregnate paper so that it shall not conduct; but that discovery has yet to be made. How many of us would be glad of a paper product which would insulate, say, as well as ebonite, to say nothing of gutta-percha, or ivory, or amber.

Among the things that come out clearly in this paper, and from what Mr. Evershed calls the instability of the liquid film, is that we do not get a constant insulation resistance or insulation conductance of moisture unless a considerable number of channels are in parallel. The significance of that, if we analyse it, is surely that conductance in a liquid is connected with movement—with the movement of the liquid itself, of the molecules or ions; because such liquids never conduct without being ionized. There is always chemical action in that sense going on, and that means movement. We may have looked in old text-books at the pictures of molecular chains across an electrical cell, and perhaps we have looked in vain for them through our microscopes: yet something very closely akin to this may be seen. If we place on a slip of glass in a microscope a film of a liquid which includes minute particles of, say, gamboge paint (a resin), or minute globules of milk, and examine the liquid when a current is passed through it, we should not see molecular chains, although we shall see small particles; but these are not in rows as represented in text-books. On the contrary we should notice lively movements, chains of twos and threes dodging about. Conductance through a liquid is always a phenomenon of lively movement, and that is going on in these tubes. Unless we can obtain a sufficient number of paths to regularize out the movement in any one chain, then, of course, we get instability. We only get statistically a kind of stability that will permit of steady measurement.

In Fig. 5 Mr. Evershed showed us the decrease of the resistance as the voltage is increased, and how the curve returns back on itself with what he, in a rash moment, described as a kind of hysteresis. We must be very careful about the use of the word "hysteresis." To my mind, if one wishes to study hysteresis one must pursue a phenomenon right round a cycle. But what would happen if the voltage were repeatedly raised to 500 and reduced to zero? Would a loop be obtained? A zigzagging curve would result until a stable bottom was reached. Mr. Evershed assures me that ultimately a loop is obtained. I am pleased to hear that, because we may be able to calculate something from that loop. I should like Mr. Evershed to deal with that point in his reply.

There is one important criticism I should like to make. I must protest most emphatically against the notion that there are any substances which do not obey Ohm's law. Ohm's law is true under all circumstances for every kind of conductor, or insulator, or current, or anything else. It depends entirely on the definition of "resistance." I do not know any way of ascertaining the resistance of a body except by passing a current through it; the name "resistance" is given to the ratio between the electromotive force that is supplied and the current which results. That is Maxwell's definition. What Mr. Evershed undoubtedly meant, and what those people mean who say that something does not obey Ohm's law, is that the resistance is not constant. When conducting a current the resistance of some substances changes because the molecular condition is being altered. If we think of a liquid carrying a current, and of all the molecular movement that is going on, can we expect the resistance to be constant whether the current is flowing or not? No, the resistance decreases as the current is increased; but Ohm's law is still true, for E/R still equals I. It is sometimes said that Ohm's law is not true if there is a back electromotive force; but so long as we do not disregard the back electromotive force Ohm's law is still true. Some people, again, get the idea that Ohm's law is not true for an alternating current merely because they neglect to insert in the equation the back electromotive force due to the reaction of self-induction. I do not know a single thing that does not obey Ohm's law. Not even in the voltaic arc is Ohm's law violated.

In conclusion, I venture to suggest to the world of electricians that to shorten the phrase "insulation resistance" we should use the term "insulance."

Mr. Beaver.

Mr. C. J. Beaver: While the paper is of more direct interest to makers of electrical machines, instruments, and apparatus than to cable-makers, we are all very much indebted to the author for his collation of facts and the very interesting demonstrations he has made, particularly those with the model insulator. Most of the phenomena referred to in the paper are familiar to cable-makers, who have always recognized the necessity for protecting fibrous insulation by non-absorbent coverings such as lead, and thereby sealing off the insulating material from contact with moisture. They have always recognized that it is impossible to maintain efficient insulation resistance in absorbent dielectrics, however well dried and impregnated these may be originally, unless such seals or barriers against moisture are employed. The absorbency of fibrous materials is due to capillarity, which means a much greater susceptibility to moisture than would be due to other effects such as condensation,

deliquescence, etc. The capillarity of fibrous materials such as those mentioned in the paper is due not only to the structure of the paper or woven fabric as a body, but also to the capillarity of the individual fibres themselves. The sequence of events demonstrated by the characteristic curve for cotton (Fig. 1) corresponds exactly to the cable-makers' experience as to what happens during breakdowns from moisture faults. The osmotic effects illustrated by the first part of the curve merge into the formation of electrolytic products in the dielectric and incipient charring in the second part, passing to final breakdown in the third part of the curve. With regard to the general character of the moisture curves shown for the various kinds of absorbent insulation and moisture films, I would point out that the fall in resistance with increase of testing voltage is simply a matter of the electrodes not making contact with the virtual conductor contained in the non-conducting mass of fibrous material. Imagine a range of materials varying from conductors, through absorbent and therefore imperfect or variable insulators, to non-absorbent insulators. At each end of the range we get a constant relation between resistance and voltage, but in the intermediate materials we apparently do not. The reason obviously is that the conducting component of these materials moves about in the cellular structure; in other words, the insulating and conducting components do not form a homogeneous mixture and are not uniformly distributed, therefore we do not make efficient contact with the conducting component and do not get a conductivity proportional to the resistance of the two components. To take a simple parallel, if we set out to measure the resistance of a stranded conductor, say of aluminium, the strands of which are making bad contact with one another, we should have to connect up every wire of the strand to the test leads before we obtained a true result. The reason for the difference between the curve for oil containing water (Fig. 21) and oil-impregnated paper also containing moisture (Fig. 22) becomes obvious when viewed from this standpoint. In the former we have a homogeneous mixture, and in the latter a collection of substances, the conducting component of which cannot make contact with the test electrode.

The "valve effects" referred to by the author have been well known in cable practice for very many years. It is because of these effects that factory tests on cables are always made with a negative current. In Government and other standard specifications it was customary until a few years ago to specify that cables should be tested with both positive and negative currents, and the results compared. A difference of not more than 5 per cent in the insulation-resistance figures thus obtained rendered the cables liable to rejection. The custom lapsed because in course of time cable manufacture arrived at such a stage of perfection that the test with negative electrification could be solely relied on. The various hysteresis effects noted by the author are probably closely connected with "valve effects." In relation to Fig. 8 the author refers to the real dielectric resistance of cables as compared with what he calls the customary resistance. It may be of general interest to point out that the customary method of testing the insulation resistance of cables by "loss of charge" is the only practical method. The real dielectric resistance is much greater than is indicated by the nominal grade or guaranteed figures. It may also be pointed out that the steadiness of the rate of "loss of charge" gives a valuable indication as to the soundness or otherwise of a cable under test, which is quite independent of the observed value at the end of the standard one-minute electrification. It is obvious that to measure the real dielectric resistance can give no advantage for cable-testing purposes over the conventional method, and the enormous difference in time required would necessitate the ratio of works area to test room area being inverted. Porcelain has been referred to in the paper and the appendix as an absorbent material, but it is not necessarily so. Porcelain can readily be obtained which is so thoroughly vitrified throughout its mass that it is non-absorbent and does not depend on its glazing for non-absorbency. Mr. Beaver.

Finally, I can hardly agree with the statement contained in the author's conclusions, that it is customary to account for breakdown by dielectric stress. As a matter of fact the primary cause of a breakdown is hardly ever dielectric stress *per se*. In the vast majority of cases, whatever the primary cause, the presence of moisture is almost invariably found to be the chief contributory cause, and as the author's work appears to confirm very conclusively my opinions in this direction, the logical conclusion to my mind is that absorbent materials should be used as little as possible for general insulating purposes unless they can be either absolutely protected—as in the case of the paper-insulated cable—from access of moisture, or free to dry out under working conditions. There are other electrical points of view from which this is highly desirable, but they do not come within the scope of this paper.

Mr. C. H. WORDINGHAM: The author has referred to "blind" tests, by which he means applying a high pressure and not knowing what goes on. I quite agree that such tests are very unsatisfactory and very unscientific; but I must say that, in my experience, I have found them exceedingly useful, and I am content to wait, as I have been waiting for a great many years, for Mr. Evershed to provide means to enable us to know what is going on. I should like to ask Mr. Evershed what is the date of Mr. Holt's experiments in Australia with the switches with porcelain bases. I know that about 1892 or 1893 Dr. John Hopkinson, with Professor Ernest Wilson's help, rather carefully looked into the effect of electric endosmosis, and I know that for some months after I had a good deal of experience with electric endosmosis on underground mains, largely on rubber cables in pipes. Reference has been made to porcelain being porous. Vitrified porcelain can certainly be obtained, and so far as I knew up to the present it was not porous; I have hitherto attributed all moisture effects to moisture on the surface of the insulator. The author does not seem to make any distinction in his paper, and probably quite rightly, between the conduction of the moisture within the material and the conduction of the moisture on the surface; but I think a great deal of the moisture must undoubtedly be on the surface. At all events, if long surface leakage paths are provided we all know that very much better results are obtained than with short paths, even though the distance measured through the dielectric may not be longer, or substantially longer, in one case than in the other. Mr. Wordingham.

Mr. B. WELBOURN: As I read this paper I could not help thinking of a well-known quotation from Browning, Mr. Welbourn.

Mr. Welbourn.

"Oh but a man's aim should exceed his grasp." I thought of this particularly at the end when Mr. Evershed suggested that the problem of forestalling breakdowns by systematic testing is nearly insoluble. Perhaps it is so, but with our present knowledge a great deal of systematic mains testing is being done, and a large proportion of insipient faults are removed from mains networks by regular testing without the consumer knowing anything at all about it. An extremely useful tool which has been provided for all mains engineers is the "Megger," for which I think Mr. Evershed is responsible, and which is an enormous advance on the old ohmmeter and generator. This in itself is a very good illustration of the rapid advance of knowledge. The author mentions, in a footnote on page 51, the flash test. I do not know whether the flash test is a "method of barbarism," but in my opinion it will not disappear very rapidly. I should like Mr. Evershed to suggest an alternative because all electrical circuits are liable to sudden pressure rises, and I do not know of any test which is in any way comparable with the flash test for showing up the suitability of the insulation to withstand these rises. I should also like to ask Mr. Evershed whether all the curves have been taken at uniform atmospheric temperatures, and whether artificial means were adopted to ensure that the insulating material was always at the same temperature, or whether the increasing dielectric loss due to the rise of the potential was allowed to heat up the dielectric. To all cable-makers especially it has been an exceedingly interesting problem to theorize as to why the insulation resistance of a cable should fall when pressure is applied and when the dielectric heats. This paper has thrown considerable light on the problem, and the author has convinced me that the theory put forward originally by Mr. Campbell and communicated to this Institution some years ago by Mr. Rayner and acknowledged by Mr. Evershed in his paper, is correct and that the effects are mainly due to moisture and air. I should further like to ask Mr. Evershed whether the fall in dielectric resistance is *only* due to moisture and air. The paper and impregnating oil themselves have physical properties which possibly change when electrical pressure is applied, and it may be that that also has some influence on these curves: but as far as I can discover from the paper the author gives no indication of his views on that point.

Now, for reasons given by the author, all the tests described in the paper have been made with continuous current, and some of them illustrate the causes of effects well known to all those whose work lies in the distribution of electricity by continuous current, such as the "valve" effect and the collection of dust and moisture through endosmosis. It reminds me of a particular use of the low-tension triple-concentric cable originated some years ago by Sir Alexander Kennedy where he made the core of the triple-concentric cable the negative pole instead of the positive pole, as is the usual practice, and I think it was effective in getting rid of some of the low insulation troubles with the neutral conductor on distribution networks. In these days when alternating-current work is so much to the fore, it would be very useful if the author could spare the time to make some tests with alternating current, and publish the results. There is no doubt whatever that the faults on alternating-current networks are far fewer—in fact almost non-existent—than on continuous-current networks. To mains engineers, the application of alternating-current pressure for some hours is a well-known method of temporarily getting rid of low insulation on continuous-current mains if alternating current is available. I think some engineers might draw the inference from this paper that if we could get rid of all the moisture and air in absorbent insulators we should approach a sort of electrical millennium; but I would ask the author if he has considered whether it is really advisable to get rid of all the moisture and air. Every attempt that cable-makers have made to get rid of moisture has only resulted in brittle paper and the destruction of that flexibility which is so essential in handling cables.

Under the general title of "Characteristics of Insulation Resistance" one can rather range outside the exact contents of the paper. I have been very much impressed in the last few weeks in re-reading Dr. Russell's paper read before this Institution in 1907.* In that paper a characteristic of insulation comes out in which moisture in a cable appears to play very little part, namely, the different behaviour of a given thickness of insulation with conductors of varying radius. In connection with Fig. 8, Mr. Evershed calls attention to the test taken after electrification for one minute, and this has already been referred to. The result is understood by all cable men as only being qualitative, but it gives an approximate idea of the true state of the insulation. Longer tests could be made if required, but, as Mr. Beaver has just indicated, there are limitations of time and space in every works.

Professor Schwartz.

Professor A. SCHWARTZ: On page 55 the author mentions that the only non-absorbent insulators which were tested in the course of his work were gutta-percha and rubber. He states that "these are both non-absorbent in the sense that what little water they may be capable of absorbing is entirely unable to form leakage paths through the insulator." While this statement may be quite true as regards gutta-percha and vulcanized rubber, it is hardly correct for pure rubber. The classical experiments of Thomas Hancock, which extended over 30 years—from 1826 to 1856—in which he hermetically sealed 12 ounces of water in a rubber bag and watched its evaporation from year to year, shows conclusively that at ordinary atmospheric pressure water is capable of being absorbed by, and of passing through, pure rubber. Pure rubber will absorb about 25 per cent by weight on prolonged immersion in water and increases considerably in volume; there is no doubt also that in its passage through pure rubber water very much affects the insulation resistance. In 1907 I tested some pure rubber flexible cables of 2,000-megohm grade; a 10-yard length was tested in air with a pressure of 550 volts, and the insulation measured between the conductors was found to be 6,000 megohms. On immersing the cable in water the insulation fell almost at once to 80 megohms; in a week to 40,000 megohms; and in 8 days it broke down with a pressure of 400 volts. A piece of vulcanized flexible cable put through a similar test showed, as in the author's case, that no appreciable effect was obtained. The amount of water that is absorbed by pure rubber depends partly on the character of the rubber, that is, on the amount of resin or oil which it contains, and partly on the physical condition of the rubber. Freshly

* *Journal I.E.E.*, vol. 40, p. 6, 1908.

Professor Schwartz.

manufactured pure rubber absorbs water readily, but if the rubber is allowed to rest it becomes hard and comparatively inextensible, and in that condition it is more resistant to the absorption of water. Mr. Lester Taylor told me some time ago, that he had had a pure rubber flexible cable feeding a 100-volt lamp for several months without any trace of breakdown, although immersed in water all the time.

I should like to refer to this question of the physical condition of rubber a little more in detail, because some of the changes that may take place in it are so considerable, and take place within such a small range of temperature, that when Mr. Evershed comes, as I hope he will do, to investigate the lower part of his curve, I think it would be interesting if he could consider the effect of these changes. (The speaker then exhibited the behaviour of a strip of rubber under the action of heat.) It is evident that the molecular condition of rubber undergoes a very considerable change at a comparatively low temperature; in determining the linear coefficient of expansion of a "rested" strip I found that this change takes place between 33° and 35° C.; up to 33° C. the rubber is in a hard and inelastic state, and above 35° C. it is in a plastic state. The author has described the state of things that obtains in the inside of a porous insulator. I have been interested in this subject from rather a different point of view, namely, in connection with the problem of the rise of sap in trees; and as a good many of our porous insulators are vegetable in origin, and since many of our inorganic insulators have a capillary structure, I think perhaps it would not be without interest if we consider very briefly what results have been reached by the physicists and the botanists who have been experimenting in this somewhat different field. In the first place we do not find in plants a continuous system of water channels; we find the bulk of the channels are intersected with innumerable longitudinal and transverse partitions dividing them up into very small compartments. It is rather curious, considering that the function of these channels is to take water from the roots to the leaves, that we should find them intersected nearly all the way up by numerous transverse partitions. We find, however, in the cells numerous air bubbles present, just as in the author's experimental tubes, and these bubbles, alternating with drops of water form Jamin's chains. The botanists consider that 10 to 50 per cent of the channels are filled with air, but I think that Mr. Evershed's resistance measurement method will help them in estimating more closely than they have been able to do by the microscope the proportion of channels which are filled with air. Now it is evident that whatever movement takes place in these chains of air and water—whether it is by endosmosis or by any other agency—the bubbles will not be able to pass through the partitions, and where we have long cells a bubble forming in one of these will put a large proportion of the conducting tube out of action, or at any rate it will introduce a very high resistance in the conducting tube. But by dividing the conducting tube up into a number of small cells by means of transverse partitions we have the size of the bubbles limited, and we see that if a cell is put out of action, or has extra resistance introduced into it by means of an air bubble, the length of the high-resistance film is limited by the length of the cell. The fact that the bubbles are confined in very small cells by longitudinal partitions means that only an infinitesimal portion of the whole of the conducting area of the circuit is interfered with by a bubble. An interesting reference was made by Professor Silvanus Thompson to the question as to whether we should ever be able to get material with pores small enough to prevent the ingress of water. I am afraid that the work of botanists shows us that the smaller the pores the more easily the water-vapour gets into them. Messrs. Brown & Escombé* found in 1900 that the diffusion of water-vapour through a number of minute pores in an impermeable membrane will be greater than through one large aperture having a cross-section equal to the area of the pores. This is due to the increased efficiency of transmission at the periphery of the aperture as against the efficiency of the transmission at the central portion of the orifice, and as the size of an aperture is reduced the relation of its margin to its area is increased. The prevailing idea in botanical circles as to the rise of the sap is that it is due to tension in the water induced by evaporation. I do not know that the possibility of an electrical cause has been considered, and I should like to ask the author in this connection what is the lowest voltage at which he has found endosmosis take place.

Mr. Rayner.

Mr. E. H. RAYNER (*communicated*): Those of us who have worked on insulation know that the labour apparent in any paper on insulation is only a small proportion of the amount which has actually been spent, a large proportion of the experimental work being the unmentioned preliminary experiments, which give the author the moral authority to publish the results of such final experiments as he deems of value. Before turning to the one point upon which I especially desire to dwell, I should like to suggest that notes on the effect of a few degrees' change of temperature would be instructive. Without experimental experience it is difficult to realize how greatly the resistance of an absorbent insulator may change with quite a small variation in temperature. The possibility of moisture being associated with mica is mentioned on page 60. When testing mica under a high voltage I have often noticed that the violence of the brush discharge on the surface diminishes after the first few minutes, which I have ascribed to driving off a surface film of moisture. Some further details as to the dimensions of the apparatus used in measuring the resistance of oil would be of use. Do the numbers in Fig. 21 refer to the actual resistances as measured, or to the value per cubic centimetre? The absorption curve for the oiled paper cable is very interesting. Does the author think the same resistance would be obtained if the paper were absent and the same quantity of water associated with oil only? And does the paper plus oil absorb much more moisture from the air than the oil alone would? Some note as to the "natural" amount of water in the paper used for the experiments in Table I would be of interest. There is no mention as to whether this condition falls within the limits of the experiments described. It is very satisfactory to find that the results of my own work mentioned on page 65 agree so well with those of the author.

I now turn to one particular point which has been

* BROWN & ESCOMBÉ. "Static Diffusion of Gases and Liquids in Plants." *Philosophical Transactions of the Royal Society*, B, vol. 193.

Mr. Rayner. mentioned by Mr. Wordingham and other speakers. On page 51 the author asks, "What is the margin between working voltage and breakdown? That is the fundamental question at the root of every inquiry into the properties of insulation. To conduct tests without any means of ascertaining what is going on in the insulator as the breakdown voltage is approached, without either observing the current or, better still, the resistance, is to shut our eyes and deliberately avoid looking for the cause of failure." And again (on page 71) he asks "whether it is possible to predict the breakdown voltage. . . . a blackened hole appears in the insulation and the inference is too hastily drawn that the puncture process was instantaneous. . . . The time may never come when it is possible, by systematic insulation testing, to forestall breakdown by diagnosis of the disease and removal of the cause." Within certain, possibly wide, limits I think weak places in the insulation, more especially where the conductivity is greatly increased by any local heating at dangerous spots. In testing small pieces of insulating cloth ample warning is given of the approach of breakdown. Whether the method can be as usefully employed for finished machines can only be determined by trial. The apparatus consists merely of a sensitive moving-coil ammeter (a micro-ammeter by R. W. Paul) and a battery inserted at any convenient part of the circuit. Small cells for pocket lamps can be mounted compactly, so that a battery giving a pressure of 100 volts weighs about 12 lb. Fig. A shows a diagram of the connections and the result of a test on three thicknesses of Empire cloth wound on a cardboard tube with tinfoil electrodes, the area being 130 sq. cm. The alternating voltage was 2,500 and the continuous voltage 100. The continuous voltage alone produced no perceptible current in the instrument. On Mr. Rayner

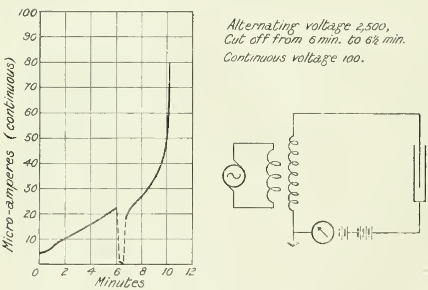

Fig. A.

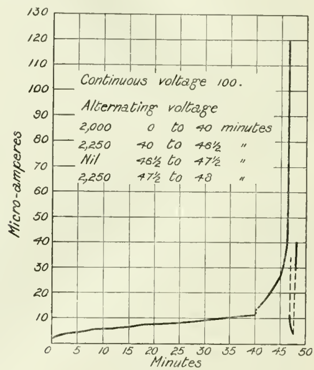

Fig. B.

the answer is already in the affirmative. It *is* possible, with *simple apparatus*, to test insulation of an organic and absorbent nature under an alternating voltage, and to see exactly what is happening; to learn whether the insulation is likely to withstand the voltage indefinitely, whether and how soon it is sure to fail, with the great advantage that the pressure test may be stopped before permanent damage is done. Some method of determining whether an electrical plant is insufficiently dried out for running for the first time after erection could not but be of great commercial value.

As the author states, alternating-current measurements are useless in showing the leakage current through insulation, as it is exceedingly small compared with the capacity current. An alternating-current wattmeter will give the required information; but it is hardly a practicable workshop instrument. It is, however, practicable, while applying a high-voltage alternating test pressure to insulating material, to add in the circuit a much lower continuous potential which will find its way through the switching on the alternating current the ammeter indicated 4 micro-amperes, which increased in 6 minutes to 21 micro-amperes. On switching off the alternating voltage the reading falls to 1 and diminishes still further. On switching on again, the alternating voltage causes instantly a great increase in the continuous current, and failure rapidly takes place.* The very great drop in the continuous current on switching off the alternating voltage is important. It shows the futility of assuming that the insulation resistance of a high-voltage machine under working conditions can be assumed from tests made by much lower continuous potentials. Fig. B shows the result of a similar test at a lower voltage (2,000), which was applied for 40 minutes and then raised to 2,250. As in the previous experiment, the alternating voltage was switched off for half a minute and the experiment was stopped a minute after switching on again a few seconds before actual failure occurred. The material has become

* E. H. Rayner. "High-voltage Tests and Energy Losses in Insulating Materials." *Journal I.E.E.*, vol. 49, p. 47, 1912.

Rayner. darker locally over an area of a few square centimetres, but actual puncture has not taken place. I do not know that the method has been tried on finished machines. It will be seen that the alternating current traverses the continuous-current instrument and causes some vibration of the pointer unless this is very stiff. The only difficulty would appear to be the alternating capacity current, which would be much larger than when testing a comparatively small piece of insulating material. No doubt a specially rigid moving system would be of considerable help and might suffice. The instrument might have a very large inductance added to it, say the primary of a switchboard potential-transformer, and the ammeter and inductance be shunted by a large condenser through which most of the alternating current passes. Mr. Irwin tells me that he has found an inductance of 4 henries and a capacity of 20 microfarads successful. The condensers should be protected by a spark-gap, as the full voltage would come on them if failure occurred in the insulation under test.

Sparks. Mr. C. P. Sparks (*communicated*): Mr. Evershed raises an interesting question: "What is the margin between working voltage and breakdown?" and suggests that the problem should be determined by continuous-current insulation tests rather than by the application of an alternating-current pressure test; the difficulty of using any sensitive instrument with alternating current is pointed out in Section 2 of the paper. While I am in agreement as to the advantage of using an indicating instrument, this has yet to be evolved for alternating current, and until this is possible I am in favour of continuing the use of alternating-current testing, not in the form of a flash test referred to in his note, but in the form of an alternating-pressure test applied for short periods. At present this is the only feasible method of testing high-pressure apparatus, and is a more reliable indication of the condition of the plant than can be obtained by a continuous-current insulation test carried out with a pressure of a few hundred volts. Section 4 of the paper refers to the relative importance in wiring between the leakage through the dielectric used to insulate cables, and the leakage through fittings. The importance of the leakage from fittings was appreciated by the Institution Wiring Rules Committee when amending the rules some years since, as is shown by the following extract from Rule 121:

"121. The insulation resistance to earth of the whole or any part of the wiring must, when tested previously to the erection of fittings and electroliers, be measured with a pressure not less than twice the intended working pressure, and must not be less in megohms than 30 divided by the number of points (par. 32) under test. For this purpose the points are to be counted as the number of pairs of terminal wires from which it is proposed to take the current, either directly, or by flexibles, to lamps or other appliances."

Section 13 of the paper deals with a model insulator tested with continuous current. Have similar tests been made with alternating current? These should show the breaking up of the films between the separate drops of moisture, thus increasing the insulation resistance. In conclusion, Mr. Evershed's paper will be welcomed by all, as it demonstrates the initial reason why alternating-current cables and other apparatus are far less troublesome to maintain than continuous-current apparatus when worked under equal dielectric stress.

Mr. A. T. Bartlett (*communicated*): I welcome the research described in the paper as one of great value, not only for the actual results already obtained but for what it may, and I hope will, lead to. Such methods and knowledge should help us to select our insulation materials in a more rational manner and, it may be, to produce new and more satisfactory forms of flexible insulators; but from the dynamo and motor manufacturers' point of view I must in common with two other speakers protest most emphatically against the author's condemnation of the flash test. I believe that few engineers understand the real object the plant manufacturer has in view when he fixes and applies a definite flash or pressure test. It is not applied, as many seem to imagine, simply to find out whether the insulation will stand a definite pressure between, say, the windings and the shell—having provided a factor of safety, he knows it will, unless the material has been damaged or has faulty spots which could not be detected before use. If any such weak points occur he wants to discover them, and I know of no other method which can approach the pressure test for this purpose, because it is not only necessary to know that such weak points exist, but they must be located, and even in "a costly piece of electrical apparatus" it is cheaper in both time and cost to burn the fault out; at this stage he is not concerned with what actually happens to the damaged insulation at the moment of breakdown. To emphasize the real object of the flash test, I may say that it has been my practice to fix the voltage of the flash test quite independently of the working voltage, *e.g.* in the case of a low-voltage, say 50 volts, generator, if I know that the insulation materials in that machine are identical with a machine built for a working voltage of 500 volts, as is frequently the case, I test for damage to the insulation with a 2,000-volt pressure test, which may appear to be heroic, but is good sound practice; I should imagine that cable-makers have probably the same object in view. Anyone who has had experience on the test-beds knows that an insulation test even when applied at a more or less high pressure by means of a 1,000-volt testing set often fails to reveal the presence of air-filled cracks in the insulation, simply because there is not sufficient power behind the test. Hundreds of cases have occurred in which machines have broken down under a pressure test after having just previously shown high-insulation results with high-voltage testing sets. The plant manufacturer can no more forgo his pressure test than can the crane- and lift-builder or boiler-maker forgo his overload stressing tests. Mr. Bartlett.

To the plant builder the experiments on the varnish-impregnated cotton-covered wire are of great interest, and my own experience agrees with the results obtained, viz. that the effect of such impregnation is quite ephemeral. I have for years unsuccessfully advocated that all field coils of such machines as are to work in an ordinary weather-proof building should be wound dry and varnished only on the outside layer, or taped over and varnished. Impregnating such coils has practically no effect on the dielectric strength to earth, and reasonably dry cotton is ample insulation between the turns and layers in a well-designed coil. I have seen a number of the old field coils of ancient two-pole machines unwound in which the cotton was in excellent condition, although wound dry. On the other

Mr. Bartlett. hand I have seen a number of cases of impregnated coils giving trouble owing to the varnish breaking down and acquiring an acid reaction; this is a real danger and one which in my opinion it is quite unnecessary to run. The author mentions stoving his varnished materials at 150° C., which I do not think can be recommended; he referred to a special varnish which he uses, and if he has a varnish that will stand this temperature not only on a thin coil such as he used, but in a normal field coil—in which the solvent in the interior takes many years to evaporate or oxidize—then I hope he will disclose it as it might be of great value in such cases where impregnation is advisable.

Mr. Campbell. Mr. A. CAMPBELL (*communicated*): As one who attaches great importance to consistent nomenclature, I regret to see that the author uses the term "characteristic curve" quite out of its ordinary meaning (*i.e.* volt-ampere curve). To give any scientific term a double meaning reduces its efficiency by much more than 50 per cent. The author's theory appears to be well supported by many experimental results, and in particular by the behaviour of his beautiful model, but I fear that the examination of a wider variety of absorptive insulating materials will make the theory more difficult to accept. Some years ago in experimenting on fibrous insulating materials (like paper) at various temperatures I came to the conclusion that the effects observed had their origin in the tubular structure of the fibres. Not long afterwards I found that solid cellulose behaved very much like ordinary paper. Now the solid cellulose is a fibreless colloidal material (like a sheet of glue), and its pores must be of a quite different order of magnitude from those of paper. Since reading Mr. Evershed's theory I have had a few rather hurried experiments made on some colloidal materials, which have given the following values for the "Resistance Ratio" for V_{40}/V_4:—

Solid cellulose	2·7
Celluloid	1·2
Cellulose acetate...	1·0

The third material is the well-known flexible enamel now so much used for covering wires; it is somewhat absorbent of moisture, but not nearly so much so as any form of cellulose. It will be noticed that the other two colloids show "Resistance Ratios" greater than unity, and yet their gluey structure does not suggest porosity in the ordinary sense. It appears to me, therefore, that the effect of moisture is mainly molecular, not explainable by the assumption of water films working in microscopic channels. Cellulose and other similar colloids appear always to have (at any given temperature and pressure) a certain proportion of water associated with them, part of which may be in loose chemical combination, and the remainder, as it were, in solution in the colloid. The tubular structure of some of the fibrous forms of cellulose no doubt must have considerable influence on their behaviour as insulators, but any theory must take account of the ultimate colloidal nature of the material. I hope the author will examine the behaviour of some of the non-fibrous absorbent insulating materials (Bakelite for example) and if necessary widen his theory to include them all.

Mr. Bairsto. Mr. G. E. BAIRSTO (*communicated*): I should like to ask the author whether in the analysis of his results he has fully taken into account the nature of the contact used in his experiments. He uses copper plates interleaved with the sheets of dielectric. Now it has been shown by Mr. Appleyard,* and recently in more detail by myself,† that in using tinfoil, which is obviously even better suited than copper plates for producing a more intimate contact with the dielectric, an increase of voltage has a very considerable influence in producing an apparent decrease in the resistance as the voltage is increased. This will take place even with a very high compression of the dielectric, say 15 or 20 lb. per sq. in. The more rigid copper plates used in the present experiments would tend to enhance this effect. There are two points described in the paper which make me suspect that the imperfect contact is responsible to a certain extent for the rapidly falling characteristic curve shown in most of the figures. The first is in Fig. 5, in which we have a so-called hysteresis effect depending upon whether the voltage is increasing or decreasing. Now this hysteresis effect is well known to those who have studied tinfoil contact with ordinary dry dielectrics, and is due to the influence of the voltage in pulling down the electrodes into contact with the dielectric. The second point is illustrated by Fig. 17, where the change of characteristic from a gradually falling curve to a straight line, as the dielectric becomes sodden with water, is explained as a change from "moisture conduction" to conduction by Ohm's law. It could, however, be explained in quite a different manner. Starting with a dielectric having a resistance independent of the voltage, curve A may be taken to represent the influence of voltage in bringing about a more intimate contact as has just been described. In curve C, however, the paper being now sodden with water will have a surface film of moisture, allowing the current to creep along the face of the dielectric from the points at which the electrode is in contact, to, and through the parts of the dielectric which are not touching the electrodes. That is to say, the effect of the presence of the moisture film is to produce a contact which is almost as good as if every part of the dielectric were in thorough contact with the electrodes. We should then get, as in curve C, a straight line showing a resistance independent of the voltage. I do not maintain that all the effects described in the paper are due to this effect, but I feel sure that it has had a considerable influence. It cannot be separated out, and the only way in which comparative tests can be made is by employing mercury electrodes. I may mention that in a long series of experiments made at University College it has been found that at low-potential gradients up to about 5,000 volts per cm. there is no variation of resistance with voltage, and this is true for such widely different dielectrics as mica and celluloid, using ordinary dry materials and mercury electrodes. As the potential gradient is still further increased the resistance falls away in a manner similar to that depicted in the lower portion of Fig. 1. Supposing, however, that the results obtained by the author represent the state of affairs for damp insulation, then it must be agreed that what we are discussing is not the characteristics of insulation at all, but rather the characteristics of water in insulation.

Mr. Gifford. Mr. R. D. GIFFORD (*communicated*): It is apparent that this paper is the outcome of a very thorough investigation. It is probably only those who have had to make resistance

* *Proceedings of the Physical Society of London*, vol. 19, p. 724, 1905.
† Ibid., vol. 25, p. 301, 1913.

Gifford. and breakdown tests on insulators who can really appreciate how fully the factors which usually go to obscure the truth have been recognized and taken account of. There is one point, however, to which I should like to call the author's attention, as I do not see it mentioned in the paper. He says, on page 53, that the source of current was usually a 500-volt battery, and occasionally a small 1,000-volt generator. The author has emphasized in several places in the paper how greatly the true value of the insulation may be masked by the capacity current, which effect must be considerable where we are testing the insulation resistance of a cable or network of feeders. Now the E.M.F. of a battery may be represented by a smooth line, but surely the E.M.F. of a generator cannot be so represented; it must have a surface ripple, since it is made up of a number of commutated waves. Under these circumstances it is apparent that a capacity current will be superposed on the insulation current, vitiating the results to a greater or lesser degree. Moreover, the ripple will be much more conspicuous in the case of the small generator E.M.F. than in an ordinary continuous-current supply, as the number of commutator segments is necessarily relatively few. I shall therefore be glad if the author will state whether he made any tests, such as with an oscillograph, to ascertain the magnitude of these ripples, and also if the results obtained when using the generator were consistent with those obtained when using the battery.

Cottle. Mr. P. J. COTTLE (*communicated*): Mr. Evershed's paper is of great interest to telephone engineers who are confronted with the problem of maintaining the insulation of dry-core cables. The pictorial representation of the action of moisture in reducing the insulation resistance of absorbent insulators may throw some light on many desiccation problems. In this country it is usual to desiccate paper-core cables with dry air, but French telephone engineers have recently extensively employed dry CO_2 for this purpose. Apart from considerations of cost and inconvenience it is claimed that a certain volume of dry CO_2 is more efficient than an equal volume of dry air for raising the insulation of a paper-core cable. It is found on the completion of desiccation with CO_2 that the insulation has been raised by an amount quite equal to that obtained by using an equal volume of dry air, but that in the former case the insulation resistance continues steadily to rise after the completion of desiccation. Does the author consider that owing to the greater density, and the consequent slower rate of diffusion of CO_2, this gas should be more effective than air in reducing the proportion of water in the paper which acts as a conductor?

Ashton. Dr. A. W. ASHTON (*communicated*): In adopting the conclusions arrived at by the author we must not lose sight of the fact that the testing pressure was continuous and that the materials tested gave results mainly determined by the amount of moisture absorbed. In cases where the leakage is neither due to absorbed moisture nor surface moisture the true dielectric leakage is proportional to the applied voltage. In the paper this is shown to be true in the case of cylinder oil (see Fig. 21, Curve A) and varnished cotton (see Fig. 24, Curve A). This true dielectric leakage, determined by prolonged charging at a steady pressure, is only of use as an indication of the presence of conducting impurities in the dielectric. On the other hand the apparent conductivity after one minute's electrification is, I believe, much more important in the case of a good dielectric than it is generally considered to be. According to what may be called the Pellat-Schweidler-Hopkinson theory of dielectric absorption, there is a direct relation between the charging current after one minute's electrification and the energy loss under an alternating E.M.F. If this theory is true the so-called insulation resistance in the case of a cable free from faults gives an indication of its capability of withstanding the prolonged application of an alternating voltage, where breakdown is probably due to an increase in temperature caused by dielectric losses. Dr. Ashton.

With regard to "blind" tests of breakdown voltage, there are two factors for the determination of which the breakdown test is of use, viz. the effect of the geometrical form of the insulator and the strength of the dielectric to resist disruptive discharge. The application of the flash test will detect the presence of faults due to design or to manufacture, and will determine whether the dielectric is able to withstand the unavoidable transient pressure rises due to switching on, etc. On the other hand the prolonged pressure test during which the material is kept under observation by measuring the energy dissipated, will enable the possibility of changes in the dielectric due to electric stress or to temperature rise to be investigated.

Mr. S. EVERSHED (*in reply*): The discussion has extended a good deal beyond the area covered by the paper, and the many interesting matters touched upon by the several speakers serve to remind us of the enormous area as yet unexplored in the field of insulation. In replying to the discussion I must, however, confine myself to those points which bear directly upon the facts recorded in the paper. Mr. Evershed.

Dr. Thompson spoke of the extraordinary difficulty there is in keeping water out of an absorbent body. At present, as he said, it seems quite impossible to keep it out, and until the great discovery, which he referred to, is made we must put up with what Nature has given us. I should like to point out that but for the marvellous power an absorbent body has of stowing away almost the whole of the absorbed water in an electrically dormant state much of the work we now do would be commercially impossible. If the whole of the absorbed water took part in making leakage paths, low-tension networks as we know them would be useless. In such networks we do not measure insulation by megohms, but by amperes sometimes a great many amperes; for the leakage current depends on all sorts of circumstances—and on the mains engineer. But if Nature had allowed all the absorbed water to conduct, then for every ampere leaking under present conditions we should have had a leakage current of many thousands of amperes. Nature is sometimes on our side. I was very much interested in what Dr. Thompson said about the inevitable instability, the complex motions, of water which is carrying an electric current. When we look through the microscope at the films in our little glass model the unstable motions are going on under our eyes. We see why individual tubes are often so extraordinarily unstable. At one moment the film water will be travelling along in one channel, and the next moment, for no apparent cause, it will divert itself into another path altogether. But this of course refers to water films on glass, and I suspect that the extremely smooth surface of the glass accentuates the

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instability. It may well be that in that respect glass is not truly representative of other insulators. Dr. Thompson asked whether the moisture curves obtained by first ascending and then descending the voltage range formed loops or not. They certainly make a loop, and there is an accompanying waste of energy. When the potential difference is applied the hydraulic force of endosmose is utilized (1) in overcoming the quasi-elastic capillary force of the film into which the dormant water is driven, and (2) in overcoming the fluid friction of the moving water. Upon switching off the pressure, the surface tension of capillary force of the film very slowly forces the surplus water out of the film into the adjacent water drops, and in so doing the reversible energy stored in the form of surface tension is all frittered away in overcoming the fluid friction incurred in driving the surplus water back into the dormant drops. Hence in going through a complete voltage cycle the whole of the energy due to the endosmose action is lost—degraded into heat. And since the surplus water retires into the drops with extreme slowness, and the flooding of the film may be made to take place almost instantaneously if we choose to apply a high potential difference, the area of the loop and waste of energy may evidently be reduced to any extent by performing the cycle with great rapidity. The analogy with magnetic hysteresis is evident. There is the "lagging behind" and the waste of energy, and if only we had the power to perform a complete *magnetic* cycle so quickly that Ewing's little magnets had barely time to move, the magnetic loop could doubtless be reduced in area to the same extent as the loop in a rapidly executed cyclic moisture curve. But the analogy must not be pushed too far.

Ohm's law is a perennial stumbling-block. I was taught to believe that it is comprised in the statement that "a current through a given conductor is proportional to the E.M.F. which drives it."* When we find a conductor in which this proportionality does not hold good (notwithstanding the fact that the conductor undergoes no apparent change in its dimensions or in its temperature), then we are justified in saying off-hand that it does not follow Ohm's law. But we do not for a moment believe that Ohm's law has failed us. On the contrary we suspect at once that our "given conductor" has in some occult way altered its electrical dimensions and changed its resistance. When we examine the case of the absorbent insulator we discover that the absorbent body which we assumed to be the "given conductor" is not a conductor at all. We find that the actual conductor is made up of a number of films of water and that each film has its sectional area increased as the potential difference increases. And in this way the apparent failure of a law which we believe to be universally true is accounted for. I have never heard the universal truth of Ohm's law more clearly expressed than it was by Dr. Thompson, and although he and I do not speak the same language I agree with every word of his statement. But I shall continue to speak the language I have been accustomed to all my life, the free and easy speech of everyday intercourse. I shall continue to say the sun rises, although I know perfectly well that he only appears to rise because I happen to live on a revolving planet.

* OLIVER J. LODGE. "Modern Views of Electricity," p. 69, edition 1889.

I quite agree with Mr. Beaver that it is commercially impracticable to measure the insulation resistance of rubber-covered cables, since each test might occupy 24 hours. I do not object to the cable-maker measuring the charging current plus leakage current at the end of one minute if the test gives him useful knowledge, but I confess I should like to see the phrase "insulation resistance" restricted to its proper use, undiluted by charging current. Mr. Evershed.

Mr. Wordingham expressed the hope that means would some day be forthcoming by which it would be possible to see what was going on while the insulation is undergoing a pressure test. The means have been available for many years past, but we have not chosen to take advantage of them. All that is necessary is a high-tension continuous-current dynamo, and a galvanometer to give timely warning of latent defects. So far from being averse to high-pressure tests, as a manufacturer I regard them as absolutely indispensable. But I want to see an improvement in the usual mode of conducting them; let us have our eyes wide open. Mr. Wordingham also drew attention to the effects due to moisture on the external surfaces of insulators. In the early stages of our research we made several attempts to investigate the law of conduction in films on external surfaces, but experimental difficulties have so far prevented us from arriving at any useful results. External films are unlikely to give a moisture curve because in the absence of drops on the surface there is no dormant water available to flood the film. No doubt the action of endosmose, if sufficiently prolonged should result in an increase in the resistance of the film, provided the water is driven away from the positive electrode at a greater rate than that at which fresh water is being deposited out of the air.

I was very glad to hear what Mr. Welbourn said about the systematic testing of distribution networks. It is indeed good to know that already a large proportion of latent defects are discovered and removed; to know that in a great many cases breakdown is forestalled. But when I refer at the close of my paper to the problem as a whole seeming almost insoluble I am thinking of the complete system, from the plant in the power house to the installation on the consumer's premises. The mains may be cut up for the purpose of testing, but it is impossible to cut up the generator and transformers, and it is in such things that the difficulties of diagnosis are greatest. It is there that our aim exceeds our grasp. Mr. Welbourn referred to a number of interesting phenomena which are familiar to the cable-maker and the mains engineer, such as the marked difference between the number of faults occurring on continuous-current and alternating-current networks, and the use of alternating current as a remedy for low insulation. These things are but vaguely known to those who, like myself, are interested in tracing the causes of such effects, and I feel sure there is room for a good descriptive paper on the subject written by someone who has first-hand knowledge.

Professor Schwartz drew our attention to the difference between pure rubber and vulcanized rubber as regards absorption of moisture. Hancock's experiment has never appealed to me as conclusive because I have never come across any rubber that did not perish after two or three years' exposure to the air, or to water containing air in

rshed. solution. After such exposure the rubber is full of minute cracks. The poor insulation results obtained with flexible cables insulated with pure rubber are, I think, as much due to imperfect joining of the rubber strip round the conductor as to porosity of the rubber. What Professor Schwartz told us about the structure of the capillary passages up which the sap finds its way in a tree-trunk (and I suppose in any plant) cleared away some of the obscurities as to the disposition of the dormant water. There are evidently plenty of cells—blind alleys—to harbour it. But where are we to place the conducting films, with all those cross-partitions apparently blocking the way at intervals along the passages? I think the answer is that since the sap goes through the partition they must be porous; and in the pores are the films, with bodies of dormant water lying close at hand on both sides of the thin wall. A disposition of that kind is particularly well adapted to produce the endosmose effect, as Mr. Finnis and I have already discovered by experiments on thin porous tubes. I can only answer the question Professor Schwartz put to me about the limit potential gradient below which endosmose will not take place by saying that I do not think there is any limit. The lowest gradient at which I have actually seen the water pouring out from a drop into the film was about 25 volts per cm.; but judging by the decrease of resistance, the effect begins a long way below that point.

While I have been investigating the first part of the characteristic curve, Mr. Rayner has been at work at the National Physical Laboratory on the last part of the breakdown curve. His method of testing by superposing alternating current on continuous current is very interesting, and the resulting effects are quite new to me. He was kind enough to communicate the preliminary results to me a few days ago, and I asked Mr. Finnis to carry out similar tests on a piece of vulcanized rubber flexible. With defective cable we get just the same kind of effects as those which Mr. Rayner has described to us. What the explanation may be is another matter. And this reminds me that several speakers have referred to the effect of temperature on the characteristic curves. When the insulator is near the breakdown point it may easily be that a large amount of power is being spent in heating it. This has already formed the subject of an interesting paper which Mr. Rayner gave us last year.* But throughout the moisture curve the power spent is almost immeasurably small, and hence there is no sensible heating of the insulator. We have never observed any appreciable rise of temperature in making tests on the first part of the characteristic curve. Replying to Mr. Rayner's question, the resistance values in Fig. 21 are those actually measured; the test was purely qualitative.

Mr. Campbell tells us that since reading the paper he has carried out "a few rather hurried tests" on colloidal materials, and he gives us the resistance ratios obtained. These are, however, no criterion for a voltage-resistance curve, in the absence of any knowledge of the shape or law of the curve. I hope Mr. Campbell will continue his investigation of colloidal insulators and give us curves based upon a prolonged experience of their behaviour.

Mr. Evershed.

Mr. Bairsto refers to the effects occurring at the contact between electrode and insulator. In the earlier stages of our research Mr. Finnis and I attempted to find an explanation of the moisture curve at the terminals, but like many other hypotheses which occurred to us, it entirely failed to provide an explanation in agreement with all the facts. It was not until we directed our attention to the inside of the absorbent insulator that we made any progress at all.

Mr. Gifford mentions the small capacity current due to the ripple superposed on the E.M.F. of a testing generator. This is of course an alternating current and does not affect the reading of the galvanometer, or ohmmeter, one way or the other.

Mr. Sparks refers to the Institution Wiring Rule No. 121 as it now stands. This rule is based on the number of pairs of terminals from which it is proposed to take current. This is very far from being the same thing as the number of leakage points, and, as I have pointed out in the footnote on page 57, it is the average resistance per leakage point which enables us to judge whether an installation is in good or bad order. Incidentally I may suggest that the ordinary wireman would more easily multiply the ohmmeter reading by the number of leakage points than perform the simplest division sum. I share his weakness. Mr. Sparks suggests that the application of an alternating potential difference should break up the films in the model insulator. I have not tested the model with alternating current, but I have little doubt that Mr. Sparks is right. I think the film water would tend to collect in a heap halfway between the surfaces of the adjacent drops; but *fiat experimentum*.

Fiat experimentum. Perhaps that is the best answer to those friendly critics of my paper who have expressed a healthy scepticism with regard to my theory of moisture conduction. Let them test a few typical absorbent insulators. Let them make up a bundle of capillary tubes and test them. Put a tube under a microscope and watch the behaviour of the drops and films. They may then feel more confidence in taking the step which I have taken; the step from what I have seen in the tube to what I infer in the absorbent insulator. On the other hand they may unearth fresh facts which give my theory its quietus. Time will show.

In conclusion, I can only say that Mr. Finnis and I shall go forward with the investigation of the breakdown curve, greatly encouraged by the cordial reception which has been given to this paper.

* *Journal I.E.E.*, vol. 49, p. 3, 1912.

DISCUSSION ON

"THE BRITISH STANDARD SPECIFICATION FOR CONSUMERS' ELECTRIC SUPPLY METERS."*

Birmingham Local Section, 12th November, 1913.

Mr. Melsom. Mr. S. W. Melsom: It is most desirable that any alteration of the existing specification should be very fully considered, and in putting forward a number of suggested new clauses as a basis of discussion Mr. Holden is doing a very real service. I do not, however, altogether agree with some of his suggestions. To take the clauses in detail:—

Clause 2.—I quite agree that it is desirable that the range of meters covered by the specification should be increased, but in view of the importance of large meters I hope that any revision will not limit the size to 500 amperes, but will include all "consumers' electric supply meters."

Clause 3.—While cast-iron or pressed-steel cases are apparently quite satisfactory for small meters, I do not think they would do for large ones. With a short-circuit current such a case would be liable to become permanently magnetized and to cause large errors in the subsequent meter readings.

Clause 6.—Mr. Holden's proposal to connect cables for currents up to 500 amperes by means of two screws clamping the cable into a hole, is somewhat revolutionary. Apart from the fact that the size of the holes he suggests would not be quite large enough to take some cables based on the Institution Wiring Rules (taking a 91/12 cable, Institution rating 490 amperes, for 500 amperes the diameter of the strand is 1·012 in. as against 1 in. allowed by Mr. Holden), the suitability of such a type of connection for large cables should, I think, be very carefully considered. Present-day practice, not only in connection with switches, fuses, and other gear, but of meter manufacturers, provides for sweating sockets for such cables; in fact, the Institution Wiring Rules provide that all cables larger than 7/18 S.W.G. must be soldered to proper lugs for connection. Meter makers almost without exception provide for 500-ampere meters either soldering sockets or flat surfaces to which copper strip can be bolted. It would be useful to have the opinion of the manufacturers as to whether it is desirable to scrap all the existing patterns for one which is probably inferior to any of those now in use. Apart from this, however, the question of connections is of the greatest importance, and I venture to suggest that the meter specification should be considered in this respect by the Wiring Rules Committee, and also with reference to any existing specification, such as that for ammeters and voltmeters, so that substantially the same type of connections might be allowed for all classes of apparatus used in a permanent installation. The manner in which cables are run to large meters is also very important, and I hope that any revised specification will deal with this point.

Clause 16.—It does not seem to be altogether desirable to rule out such meters as the electrolytic and the commutator ampere-hour meter, which require a pressure drop of about 2 volts, and I therefore think that the 2-volt drop should stand for small meters. With regard to the voltage drop suggested for large meters, Mr. Holden's figures are no doubt based on shunted meters. So far as present practice is concerned I think that the limit of 0·075 volt suggested is too low and that for large shunted meters it should be of the order of 0·2 volt. The loss of power even for a large meter would not be excessive, and I think that most people would prefer to lose rather more power if by so doing they could obtain a more accurate meter. For unshunted meters, however, this limit is too high, since such an amount of power dissipated in the meter itself would give rise to large errors due to heating, and I would suggest therefore that there might be some differentiation between shunted and unshunted meters, specifying a maximum voltage drop for the former and a limiting number of watts for the latter. Mr. Melsom.

Clause 17.—While for alternating-current meters the limits suggested by Mr. Holden may be satisfactory, I would point out that for a 480-volt continuous-current meter the limit of 7 watts which he suggests (about 1·5 watts per 100 volts) is much lower than that required for the great majority of meters, and I shall be interested to learn whether in his opinion a motor-type meter can be made to work satisfactorily with such a small loss in the pressure circuit.

Clause 20. *Accuracy*.—I note that Mr. Holden suggests the same limit of error for both large and small meters, and I should like to have his opinion as to whether, when taking into consideration all the factors involved, a small meter can be expected to conform to the same limits of error as a large one. I do not suggest that the limits for, say, a 10-ampere meter should be increased, and perhaps I might put it in another way, namely, whether it is not desirable that a 500-ampere meter, where a year's record would probably represent several hundred pounds sterling, should work to a somewhat higher degree of accuracy than a small ampere-hour meter in which the year's record would probably be represented by only a few pounds. I admit that it is a purely commercial question with which perhaps I am not competent to deal, but probably we shall have some expression of opinion from those who are more conversant with the commercial side of the question.

Clause 26. *Wave-form*.—Mr. Holden's suggestion of a limit of error for a change in wave-form would, I think, be very difficult to apply. In testing, it would involve the production of a wave-form with all the possible harmonics, and it seems probable that such a clause could not really be applied in practice. Generally speaking, one would expect that a meter which is unaffected by large changes in frequency would not be affected by slightly varying wave-form.

* Paper by Mr. S. H. Holden (see p. 39, No. 223).

Melsom. *Overload.*—With regard to overload capacity, Mr. Holden thinks that such a clause should be deleted, but at the same time I would point out that practically all meters will stand large overloads for short periods, and, moreover, the deletion of such a clause would tend to the undesirable practice of installing meters which are far too large for the average load. Particularly is this the case in traction meters, where the current may rise for a few seconds to about five times the normal full load. The question of overload for meters used on a traction circuit will, I hope, receive careful consideration in any new specification. I regret that time has not permitted of my dealing fully with Clauses 25, 26, and 27, but I hope that these clauses will be discussed by other speakers.

ttock. Mr. R. A. CHATTOCK: I think it is quite time that this specification should be revised and brought up to date, and the suggestions made by Mr. Holden should be very valuable for this purpose. I do not agree that frequent revision of the specification is necessary, and I consider that once every five years is quite sufficient; oftener than this would render the specification practically useless for commercial purposes. The author emphasizes the point that the specification should be sufficiently rigorous to exclude all but the best articles, but he does not indicate how this should be done. This is the most important consideration from the purchaser's point of view, and I suggest that the only feasible way of ensuring that the best materials and workmanship are used is to require a long period of guarantee, covering the accuracy, material, and workmanship of the meter. The specification requires only one year's guarantee for accuracy, and three years for defective material and workmanship. I understand that it is usual to guarantee gas meters for a period of five years under all these headings, and I consider that five years should be the period required in connection with electricity meters; if this were insisted upon, it would ensure that the manufacturers put the best materials and workmanship into their goods. Defects in meters very often show up two or three years after the meters have been installed.

Under Clause 17, the author states that the consumption in the pressure circuit of single-phase meters should not exceed two watts, and for continuous-current meters seven watts at the declared pressure; it is not clear whether these figures are per 100 volts, or refer to the total voltage, whatever this may be. The specification calls for four watts for each 100 volts of pressure; this appears to be too high, and I suggest that two watts per 100 volts of pressure is sufficient for both alternating-current and continuous-current meters. In Clause 20 I agree with the author that the stipulation as to accuracy is too clumsy for ordinary use. The usual requirement for meters is an accuracy of $2\frac{1}{2}$ per cent up or down from full load to $\frac{1}{20}$th load. This is perhaps too rigorous for small meters, and I suggest that an accuracy of within 2 per cent up or down from full load to $\frac{1}{20}$th load for meters of 10-amperes capacity and upwards, and from full load to $\frac{1}{10}$th load for meters below 10 amperes' capacity, should meet the case satisfactorily. I cannot quite understand why continuous-current ampere-hour meters should only be required to have an accuracy of within 2 per cent down to the limit of $\frac{1}{2}$ ampere. This limit is certainly too high for some sizes and too low for others. As regards Clause 27, it is not clear if this allowable 2 per cent error is to be in addition to the ordinary 2 per cent allowable inaccuracy. I consider that meters should be accurate within 2 per cent up or down for any power factor between unity and 0·25, and this should be the total allowable inaccuracy from whatever cause. Mr. Chattock

Mr. E. FAWSSETT: I find myself in complete agreement with the author in his contention that this specification does not go far enough. It ought to exclude from compliance all but the very best practice; but although I have had a copy for several years, we have always asked for and been able to obtain much better performance in several respects than is necessary merely to comply with the terms of this standard. The proposed alteration to Clause 2 is good; some makers' sizes go up in steps of 40 amperes, which is a needless complication; all good modern meters have a wide range of accurate registration, so there is no need for further intermediate sizes. Apparently the specification did not contemplate anything in the way of a power supply, and while I do not suggest separate treatment for alternating-current and continuous-current meters, the former certainly require several additional clauses, especially if polyphase meters are included, as I consider they should be. There is room for great improvement in the interpretation put on Clause 5 by the meter makers. The last part of Clause 9 refers to labelling as to temperature of adjustment and coefficient; so far as I know, the British Thomson-Houston Company are the only firm who do this. I note with some amusement that the author is discreetly silent on the subject; I hope to refer to this directly under Clause 28. In the author's suggestions on Clause 10 he specifies "drillings" for the label holes, which label he immediately afterwards says is too small. I certainly agree that it is; 3 in. by $\frac{7}{8}$ in. is a much better size, the holes being $\frac{1}{8}$ in. diameter and $2\frac{3}{4}$ in. apart. Clauses 12 and 13 if taken together would in a large power meter require eight separate indices besides testing dials. Such a number is, I think, unnecessary, and tends to wrong readings. I suggest a table of dial constants for large powers somewhat as follows (we attain full loads of over 10,000 kw. on a single meter already, and this specification ought to look ahead):— Mr. Fawssett.

	Full Load in Kilowatts	Value of 1st Index	K
Not exceeding	200	1 unit	1
Above 200, not exceeding	1,000	10 units	10
„ 1,000, „	10,000	100 „	100
Over	10,000	1,000 „	1,000

On very large power meters the unit dial, if there were one, would travel faster than the disc and be a needless source of friction. I would not specify testing dials for large meters above the author's suggestions for 200 kw., as Clause 9, Sub-section 6, provides the necessary information. The author's additions to Clause 16 are excellent, although I would not go below one-tenth of a volt for large sizes as he proposes. Of course the figure of 15 watts in the specification does not take into consideration large meters; more than that is necessary and, moreover, is absolutely insignificant. Consider a 2,000-ampere 240-volt continuous-current shunted meter; on full load with a shunt drop (main circuit) of 0·1 volt, the energy loss is only 4 ten-thousandths of that recorded by the meter, and is small

[Mr. Fawssett.] even compared with the probable improvement in accuracy over using, say, half that drop; at quarter load it would only be 1 ten-thousandth of the recorded load. Clauses 19 and 20 are both too lax for the present day, and I think the author's suggestions meet the case, though I consider the lower limit in Clause 20 might be less. I would make it read as follows: "The error of a meter . . . shall not exceed 2 per cent between full and one-twentieth loads, except that meters below 5 amperes capacity shall not be required to conform to this below 0·25 ampere." I think Mr. Holden's suggestion for alteration of Clauses 25–27 is rather too favourable to the manufacturers. Behaviour under pressure and frequency changes is a question of design rather than adjustment, whereas the ordinary accuracy test depends on adjustment, so that I think the word "cause" should stand.

Clause 28 makes a half-hearted attempt to deal with temperature. These are the most serious errors in many types of meter, and the least often tested for, or indeed realized by many. In an ordinary house in winter, temperatures ranging from 40° F. in the cellar to 90° fairly high up on the kitchen wall are quite ordinary, and both these places are quite usual positions for meters. All the alternating-current meters which I have examined are fairly good on this score, but most continuous-current meters are very bad. I have included a small table

Letter	Type	Temp. Coeft. (Fahr.)	Degrees Fahr. for 1% change	If Correct at 60° F. Registration at 40°	90
A	A.C. Watt-hour (Induction)	− 0·06	16·7	98·8	101·8
B	C.C. Watt-hour (Commutator)	− 0·25	4	95	107·5
C	C.C. Watt-hour (Mercury shunted 800 amp.)	+ 0·15	6·7	103	95·5
D	C.C. Ampere-hour (Mercury 3 amp.)	− 0·193	5·2	96·1	105·8
E	C.C. Ampere-hour (Mercury 10 amp.)	− 0·166	6	96·7	105·0
F	C.C. Ampere-hour (Mercury 50 amp. shunted)	− 0·082	12·2	98·4	102·4
G	C.C. Ampere-hour (shunted commutator)	+ 0·142	7	102·8	95·7

showing what these mean, and as an example let us suppose a mercury meter is fixed to check a commutator meter (ampere-hour in both cases), both being correct at 60° F. in the test room. In the consumer's cellar the commutator meter then appears to be 6 per cent fast, but in his kitchen 9·3 per cent slow. A reasonably close guarantee for temperature would debar from compliance nine-tenths of the continuous-current meters in use to-day, but yet something ought to be done or electrical engineers must admit that, after all, our cherished accuracy of measurement is no better than that of the gas meter. Indicating instruments are far better in this respect, so the problem ought not to be insoluble. As a fillip to the makers I suggest that Clause 28 should read "A variation of 10 degrees F. above or below the standard temperature shall not cause an error in respect of such variation of more than 1 per cent." [Mr. Fawssett.]

To include polyphase meters and provide against some of their special sources of error some new clauses are necessary, and I suggest something on these lines: "A meter intended to measure true power in a polyphase circuit shall be constructed on the 'two-wattmeter' principle, and shall not show a greater divergence than 1 per cent on reversing the direction of both the current and pressure in either or both elements, and no more than 3 per cent change between 0·5 polyphase power factor, current leading, and current lagging. Pressure transformers for use with such meters must, when supplied within 10 per cent of their rated voltage and at the correct frequency give a ratio, when loaded with the meters, not differing more than ½ per cent from the correct ratio. Under such conditions the phase angle must not exceed one-tenth of a degree. Current transformers for use with such meters must, when loaded with the meters, and at the correct frequency, maintain their correct ratio to one-tenth of full load within 1 per cent, and to one-twentieth of full load within 2 per cent, and the phase angle shall not exceed 1 degree from full load to one-tenth load, nor vary more than 1 degree between full load and one-twentieth of full load.

Dr. C. C. GARRARD: I consider that it is of the utmost importance that the specifications issued by the Engineering Standards Committee should be thoroughly discussed. I have found the specifications of the greatest use, and anything that can make them more widely known and used is to be welcomed. The meter specification under discussion is priced at 5s. per copy, and the words "copyright, all rights reserved" are printed on the cover. Mr. Holden's suggestion that copies of the specification should be sent out with tenders is excellent, but the price of 5s. per copy is prohibitive. I moreover cannot see the object of such a price, as the printing of the specification cannot cost that sum, and I do not understand why the right of duplication is withheld, as the whole object of issuing the specifications is to make them as widely known as possible. Would it not be possible for the Engineering Standards Committee to give permission, on application, to make printed copies of the specifications, so that any manufacturer may prepare copies in the style that best suits himself? [Dr. Garrard.]

I am in general agreement with the alterations to the standard specification suggested by Mr. Holden, but I should like to make several remarks and further suggestions in connection therewith. As regards Clause 2, I prefer a 2½-ampere size instead of a 3-ampere size for both continuous current and alternating current, as it is exactly half the capacity of the next larger size, and it is very convenient to have this exact relationship. The 75-ampere size might well be deleted, and I do not consider it necessary to have both a 250-ampere and a 300-ampere size. With regard to cases, iron has the great advantage that it magnetically shields the interior. Mention has been made in the discussion of a cast-iron case meter which developed a 16 per cent error due to a short-circuit passing through

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it. This must have been a very bad type of meter indeed, and this instance does not alter the fact that, other things being equal, an iron case does act as a magnetic shield. I think, however, it would be bad to exclude all other cases, for example, those of aluminium. These have the advantage of lightness, which is of great importance in the the export trade. As regards Clause 6, I agree as to the provision of the two clamping screws, and do not consider sweating sockets an advantage. Mr. Holden suggests (Clause 10) that the meter cases should be sent out with two holes drilled in them to take the rivets for the name plate; would these not allow the admission of dirt? I also agree with Mr. Holden's recommendation as regards the provision of springing figures on the cyclometer dial. Under Clause 12, Mr. Holden objects to the use of the word "unit," but I would point out that the meaning is clearly given on page 4 of the specification under "definitions." Moreover, I think the word "unit" is more easily understood by the general public than the words "kilowatt-hour." In Clause 9 of the specification, as now worded, it is only required to state the temperature coefficient of the meter "if necessary." I suggest that these two words be left out on account of vagueness. It is quite possible that the manufacturer of a meter having a large temperature error may not think it necessary to advertise this fact on the front of the meter, whereas it is quite possible that the purchaser may have a contrary opinion.

Mr. Chattock has suggested that manufacturers should be called upon to guarantee meters for five years. I must express strong disagreement with this. In the first place it is no additional safeguard to the purchaser, as a motor or clock meter which will work well for one year will certainly, with proper attention, last ten years or longer. A five years' guarantee may mean either a very large expense to the manufacturer or a very small one, depending upon the care taken with the meter and the reasonableness of the user or supply authority. In any case it is something which cannot be accurately evaluated. In the long run the manufacturer would have to cover himself by considerably increasing the price. It is well known that during maintenance periods manufacturers are often called upon by unreasonable users to carry out work and incur expense which are not within the terms of the guarantee, and the manufacturer will often do this rather than incur the odium of defending his just rights. I regard the demand for a five years' guarantee for meters really as an absurdity and as being of no real value whatever to the purchaser, and I would strongly oppose it. With regard to current transformers, which have been mentioned in the discussion, I suggest that the maximum phase error allowed should not exceed one-half of one degree.

The most serious blemish of the present specification, in my view, is Clause 18, which fixes the insulation test. In the first place the application of a continuous-current voltage of between 1,000 and 1,500 volts as called for, is not very convenient. Moreover, merely to fix a minimum insulation resistance is not sufficient. The only satisfactory method of test is to apply an alternating-current voltage of the required value. No doubt for small house-service meters on consumers' premises a test pressure of 1,000 volts (continuous current) is in many cases enough. When one comes, however, to large sizes, which are nowadays frequently installed on switchboards belonging to large consumers, instead of the so-called switchboard type, and where the working voltage is very likely between 400 and 500 volts, it is not sufficient. As, moreover, it does not cost materially more to insulate a meter as I suggest than for the lower test pressure, all should be made alike. The clause as altered according to my suggestion would read: "The insulation resistance between all the electric circuits . . . and the case should be tested by the application of 2,000 volts (r.m.s.) alternating-current pressure, having a sine-wave shape, for a period of 15 minutes without any sign of breakdown." The corresponding test pressure between the main circuit and the pressure circuit to be 500 volts (alternating current). Mr. Holden further suggests that the standard sizes should be extended to 500 amperes. In many cases such large meters would be worked by current transformers. This being so, it would be necessary to specify the amount of the secondary current, as has been done by the Standards Committee in the case of ammeters. Dr. Garrard

Mr. W. LAWSON: Undoubtedly the weakest feature of the existing specification is in the two clauses Nos. 31 and 32 covering latent defects and impaired accuracy. The prevalent impression that electricity meters are an unreliable class of instrument is attributable partly to the influence of these clauses. They have also presented a low standard of service requirements to manufacturers, who, in consequence, have concentrated their efforts on minor and sometimes negligible improvements in performance under test. Those guarantees are of the utmost importance to consumers and supply authorities, and in the case of the former it is specially desirable for the avoidance of disputes that they should have confidence established in the meters registering their supply. Accuracy in a meter can easily be ascertained, but supply authorities are at a disadvantage in estimating its probable reliability. The strength of guarantees is a direct measure of the faith held by a manufacturer in his own productions, and for the protection of buyers rigorous guarantees should be specified. With regard to Clause 9, I suggest that all meters conforming to the British Standard Specification should have the words "British Standard Meter" engraved on the maker's label. I object to Mr. Holden's suggestion that in the case of "jump" cyclometer-type dials the first dial denoting units should move at a uniform speed, as such an arrangement would lead to errors of reading. I may mention the case of a meter that has registered 99 units and has very closely approached the 100 figure. The 9 on the units dial will have practically disappeared, whilst the 0 would be in full view so that the reading will appear to be 90, or 10 units below the actual. I doubt the advisability of substituting the expression "kilowatt-hour" for "unit." The latter expression has now passed into the language and any effort to dislodge it will in all probability suffer the same fate as all other attempts at altering popular nomenclature. With regard to the allowable drop in $2\frac{1}{2}$- or 3-ampere meters, I consider the 2-volt limit as now specified should stand. My experience with 1,000 meters having about a 2-volt drop is that it does not seriously affect the consumer's voltage. In respect to watts lost, as the average load on a 3-ampere meter amounts to only about 1 ampere, the watts lost come to about one-third of one per cent, which is not a serious matter in a quarterly account of, say, 12s. Mr. Lawson

Mr. Lawson. The specification for testing requirements of polyphase meters is a matter of considerable difficulty, but I suggest the following: Meters intended for use on polyphase circuits, whether for balanced or unbalanced loads, and where the neutral point is not available, should be constructed on the principle of the two-wattmeter method of measuring polyphase energy. Where the neutral point is available and current is to be taken between the neutral and any of the lines, meters should be constructed on the three-wattmeter method. This latter is absolutely necessary in the case of induction meters operated by transformers. The meter should be composed of single-phase elements magnetically isolated from each other so that there is no interaction between them. Each element should be adjustable to read correctly between 2½ per cent plus or minus at all loads, from full load down to one-twentieth load (watts), and at all power factors from unity down to 0·25. When tested on polyphase current, the meter should be correct within 2½ per cent plus or minus from full load down to one-twentieth load (watts), at all power factors from unity down to 0·5. In the case of 2-phase 3- or 4-wire and of 3-phase 4-wire meters, a test down to 0·5 power factor would be sufficient for both the single-phase and 3-phase tests. All tests should be carried out in conjunction with current transformers if such are used to operate the meters. The use of balanced-load meters should be prohibited for consumers' supply.

Mr. Shaw. Mr. C. M. SHAW: I am doubtful whether the efforts of the Engineering Standards Committee are so beneficial as one could wish. The present paper offers an opening to broaden the work of standardizing meter practice. Having had the benefit of investigating many of the finest organizations, large and small, in America, I was particularly impressed with the superior methods of maintaining meters after purchase, which is more important than quibbling about refinement of design. All seem to work on common lines without duplication. This is due in a large measure to their adopting a Meter Code, and I cannot do better than read abstracts from the preface of this publication :—

"It was the ambition of the associations to produce a reliable and up-to-date manual covering the many phases of electric meter practice as encountered by all companies, both large and small. It was the committee's belief that such a code if intelligently prepared would prove of great value, not alone to those actively engaged in operating meters but also to those interested in the practice of metering from other standpoints, namely, official, legal, etc. There was also found an urgent need of a closer agreement between the manufacturers and the operating companies as to reasonable and satisfactory specifications covering operating and design. The development of such a code with the collecting of the very large amount of data was placed in the hands of the Electrical Testing Laboratories of New York. As a means of increasing the strength and support of the work, and at the same time avoiding duplication of effort along similar lines, many associations joined hands for the further development of the code. It is hoped that it may find its place amongst the reliable books of reference in the hands of those responsible for and interested in the purchase, installation, and operation of electric meters. Whilst the code is naturally based upon scientific and technical principles, the commercial side of metering has been constantly kept in mind as of great importance." Mr. Shaw.

An active and representative committee of operating engineers and representatives of makers and testing institutions have the duty of considering developments in all branches of meter practice, and a report is presented by a chairman to the various bodies each year. This report often provides matter for keen discussion at association meetings, and any improvements after general approval are then incorporated in the code, thus bringing it up to date each year. I cannot but think we could co-operate on similar lines to the benefit of all concerned. Personally I have obtained much benefit by following the procedure set out in this meter manual.

Mr. A. E. JEPSON: While agreeing with many of the points brought forward by the author, I should like to point out to him that many of his suggestions do not take into account the numerous meters of large size which are at present supplied. With regard to Clause 2, probably the 2½-ampere size is preferable to the 3-ampere size, but if it is proposed to make it standard for single-phase meters, then it should be made standard for continuous-current meters. I think the 75-ampere size should stand, for on a 200-volt continuous-current circuit this equals 15 kw., which is a very handy size, and on a three-phase circuit with a line pressure of about 400 volts it is approximately equal to 50 k.v.a., which is also a convenient size. I agree with Mr. Melsom that if sizes are to be specified, then standard sizes should be given for meters up to, say, 10,000 amperes. With regard to Clause 3, I think the suggestion of the author is rather unfortunate. His statement that cases of soft metal or sheet jointed together are not used on the highest class of meters will be hard to uphold, for in the single-phase meters made by the British Westinghouse Company, the British Thomson-Houston Company, and the Aron Electricity Meter Company, aluminium cases are used, which can be described as soft metal. Aluminium cases have been found to withstand all sorts of climates and all conditions of humidity, and, further, when they are pressed in one piece they are quite strong enough for the ordinary usage to which meters are subjected. With regard to cases of sheet jointed together, those used on the clock-type and polyphase induction meters are found to be quite satisfactory, and I think this is a question which should be left entirely to the manufacturers and their customers. A cast-iron cover is inclined to give a false sense of security, for any meter containing magnets, even though shielded by a cast-iron cover, can be affected by stray fields if the latter are strong enough. Mr. Jepson.

Clause 6.—The proposal to have two clamping screws may be all right on the smaller sizes, but I am of the opinion that for the large sizes the clamping of screws on to a cable is quite unsatisfactory if sweating thimbles are not used.

Clause 10.—I think this clause might very well be deleted, for various customers require various particulars on the labels of their meters. With regard to riveting the labels on the covers, I think this is not quite satisfactory, as many corporations are averse to breaking the seals on meters until the guarantee period is past, and it is not always convenient to send the labels to the works to be fixed.

Clause 11.—This does not seem to allow the ordinary slow-moving roller type of cyclometer dial to be used, but

Jepson. I must say there is a considerable demand for this type of counter, particularly by the smaller Corporations. There is not much doubt in this type as to which of the two figures is to be read, and I am afraid that if this clause is made to exclude such types, many Corporations will not use the standard specification when sending out inquiries for meters.

Clause 12.—I am of the opinion that the expression "units" is better than "kilowatt-hours" for the same reason as that mentioned by Mr. Lawson. We are so used to the word "unit," and the consumer is also so used to it, that confusion would be sure to arise if the word "kilowatt-hour" is substituted. In the case of very large meters it is very often the case that the last dial reads in tens or even in hundreds of units, and consequently the alteration to the clause might have included sizes above 200 units per hour.

Clause 16.—This is not very applicable to large meters, particularly of the shunted type, for the loss considerably exceeds 15 watts. The question of pressure-drop is rather important, for meters of the commutator type require at least 1 volt drop, and if a maximum of 0·75 volt were specified, then radical alterations would have to be made to the design of meters of this type. For meters above the 150-ampere size no particular figures are specified for the pressure drop, but in the case of shunted clock-type meters at least 0·2 volt is required.

Clause 17.—With regard to the consumption of energy allowed by this clause, a distinction should be made between alternating-current and continuous-current meters, and it will probably be better to state the watts loss per 100 volts instead of taking the figure of 7 watts for a maximum of 650 volts.

With regard to the suggestion *re* a test with varying wave-form, I agree with Mr. Melsom that instead of inserting Mr. Holden's suggestion about the variation of wave-form of 10 per cent from a true sine curve at any point, it would be better to specify that the meter shall not vary more than 1 per cent when the supply is varied "n" per cent in frequency when using the true sine wave. With regard to Mr. Lawson's suggestions *re* 4-wire meters for three-phase working, his proposed specification does not allow the use of two elements with three current windings, and as this particular type has quite a large field of usefulness, I think it would be better to include it if a clause is inserted dealing with polyphase meters.

James. Mr. S. JAMES: I should like to endorse the author's remarks with reference to standard sizes. There is no advantage to be gained by having a large number of standard sizes, but there is a decided advantage in favour of a small number, both from a manufacturer's and from a user's point of view. The great thing is to decide what sizes are really necessary and then to work to them. American standards differ from German standards, and both are different from the British Standard Specification. All are to be obtained in this country, and there are at least 20 so-called standards to be obtained below 100 amperes; an unnecessarily large number. I agree with the author that a $2\frac{1}{2}$-ampere meter is to be preferred to a 3-ampere, at any rate for alternating-current meters, because a standard set of gears to fit $2\frac{1}{2}$-, 5, and 10-ampere meters, all running at standard speed will also fit 25-, 50-, and 100-ampere meters with no alteration except a change of dial. The dials for the last three, of course, read ten times as much as the first three. A 75-ampere meter is quite unnecessary, just as unnecessary in fact as a $7\frac{1}{2}$-ampere meter between the 5- and 10-ampere sizes. With regard to the additional standard sizes suggested by the author, I venture to say that the 150-ampere and 250-ampere meters are unnecessary, there being an ample range with 100, 200, 300, 400, and 500 amperes. Mr. James.

Clause 6 in the specification deals with the terminal compartment. The latter portion of the clause evidently refers to watt-hour meters, and the wording suggests a three-terminal connection. This method of connection is out of date and is considered bad practice by most engineers, although some still profess a liking for it. The chief objections to it are that by breaking off the potential lead the registration of the meter is interrupted, although the consumer still obtains a supply of current. It is not a difficult matter to arrange that the meter shall be registering when a visit from the meter inspector is expected, and fraudulent practice may go for a long time undetected. Further, by inserting a wire in the fourth terminal which is provided for testing purposes, current may be obtained without being metered. I suggest, therefore, that the second part of Clause 6 be altered to read: "Watt-hour meters or meters having a pressure circuit shall have the terminals adapted for both the mains to pass through the meter." This would prevent the meter being tampered with as suggested above, and has the further advantage that a joint on to the main which does not pass through the meter in the three-terminal method is unnecessary. A uniform method of connection would be an advantage, and I suggest (1) that bottom terminals only be recognized; (2) that the main terminals should be on the left- and the consumers' terminals on the right-hand side. With a standard method of connection there would be less chance of a meter-fixer making a wrong connection. Clause 9, sub-section 6, says the meter shall bear a label marked with the speed of the rotor in revolutions per minute at full load and at the standard temperature, or at the option of the manufacturer the number of revolutions of the rotor in registering one unit. The latter method is to be preferred, and if universally employed would considerably simplify meter testing.

Clause 23 specifies that the meter shall not be injured and its accuracy shall not be permanently impaired by passing for a period not exceeding half a second a current in the main circuit not exceeding 30 times the capacity of the meter. This is a difficult test to carry out satisfactorily for obvious reasons, and I suggest the following as being more practical: "The meter shall not be injured and its accuracy shall not be permanently impaired by direct connection across the mains through a fuse of double the rated capacity of the meter." This test approaches more nearly to service conditions than the specification test.

The author suggests the use of the expression "kilowatt-hour" instead of "unit." I should like to endorse that. "Kilowatt-hour" is understood all over the world and "unit" is not. Some countries importing British meters do not recognize the term "unit" or "Board of Trade unit," and the Board of Trade is unknown. The average consumer in this country would be just as contented if his meter was marked "kilowatt-hours." He does not know what a unit represents, except that it is that for what he pays 6d. or whatever price it may be

Dr. Kapp. Dr. G. KAPP: I should like to point out that there is a difference in the working conditions between a meter tested in the laboratory and the same meter in regular service on a consumer's premises. This difference is recognized by the German rules, which allow a greater error in the latter case. In the standard specification discussed by the author it is not stated whether the permissible error refers to laboratory tests or to the commercial use of meters. I think that the important point is the performance of the meter in actual service; for this reason meters should be tested *in situ*. In view of the disturbing influences, such as temperature variation, vibration, moisture, etc., to which meters may be subjected when in commercial use, it would be justifiable to have two scales of permissible percentage error: at any rate it would be necessary to state whether the scale given in the specification and the amendments suggested by the author refer to laboratory tests or to the working conditions of the meter. I hope the author will make a definite statement on this point in his reply.

Mr. Taylor. Mr. A. M. TAYLOR: I wish to refer to the use of instruments on high-tension alternating-current three-phase switchboards, viz. to those on the generators and on the outgoing feeders. In the case of the generator meters the points to be guarded against are errors introduced by the loads on the three phases not being equally balanced, also those due to the varying power factors of the load. In the case of the instruments on the feeders there is the error introduced by the insertion of relays, ammeters, power-factor indicators and, occasionally, "trip" coils in the secondary circuit of the current transformers. This changes the ratio of the transformer, and thereby introduces errors. Without pretending to offer more than a suggestion as to how these errors should be guarded against, I wish to put forward the following clauses for consideration: (1) The accuracy of the meter must not be affected by the load being unbalanced, provided that the load on no individual phase differs by more than 20 per cent from that in either of the other phases. (2) The meter must be suitable for working with any other apparatus supplied from the same current transformers, and with this object the meter shall be tested in conjunction with the current and potential transformers with which it is to be used, and the limits of accuracy determined upon shall be understood to embrace the errors introduced by a 2 per cent change in the ratio (see Clause 3, following) of the current transformer to be employed. (3) The current transformers that are to be used shall have a change of ratio which is not more than 2 per cent over the normal range of load, and this must include errors caused by the use of protective relay coils (exclusive of "trip" coils) or ammeters or power-factor meters having small values of impedance. If trip coils are used, the change of ratio should still not exceed 3 per cent. (4) The accuracy of the meter must not be affected by the power factor of the load within the limits of unity and 0·6. The errors in the meter itself, due to the interaction between the elements, and the difficulty of testing the elements by means of single-phase coils independently of one another, have already been dealt with by another speaker, and I am substantially in accordance with his recommendations.

Mr. Ratcliff. Mr. H. A. RATCLIFF (*communicated*): The author's criticisms and suggestions are very reasonable, and with most of them I am in complete agreement. The specification in its present form does not protect the purchasers of meters to a sufficient extent, and in fact it may possibly have the contrary effect, since there are on the market many meters which would comply with the requirements of the specification and which are nevertheless thoroughly unreliable. It is perhaps rather questionable whether a specification drawn up by a committee essentially representative of many varied interests can ever be very exacting in its requirements, and for this reason matters of technical detail will probably always have to be left to individual specifications based upon actual experience of the good and bad features of a large variety of meters. A good specification should be as widely applicable as possible to all well-made meters having an established reputation, and it should above all things be free from unreasonable fads. It must, however, rigorously exclude the cheap and inferior meters mentioned by the author. The useful purpose of such meters is not quite apparent. The following notes deal with several clauses of the specification in addition to those criticized by the author. The specification covers both continuous-current and alternating-current single-phase meters, and under "Standards and Definitions" it states that the British Standards of Electrical Quantities shall be the legal standards in the custody of the Board of Trade. So far as I am aware, there is no legal standard of electrical power as distinguished from the mere product of volt and ampere measurements, which is obviously inapplicable to the requirements of several clauses in the specification. A footnote refers to the use of a suitable wattmeter, but it is very doubtful whether at the time the specification was drafted the Board of Trade possessed such an instrument, and even at the present time it is extremely difficult to say what may be regarded as a really reliable standard, although much valuable work by Messrs. Rayner and Paterson at the National Physical Laboratory has materially advanced the establishment of such a standard.

Clause 1 leaves much to individual interpretation and judgment. With regard to Clause 2, I agree with the author that the $2\frac{1}{2}$-ampere size is preferable to the 3-ampere size for single-phase meters, and I would also suggest this size for continuous-current meters; 75 amperes is an unnecessary size, and probably also 150 and 250 amperes. Experience has shown the following to be useful:—$2\frac{1}{2}$, 5, 10, 25, 50, 100, 200, 300, 500, and 1,000 amperes.

Clause 3.—Unfortunately cases of soft metal or of sheet jointed together are used on some of the highest class of meters. For small meters cast-iron cases are probably most suitable, but the weight is almost prohibitive for large sizes, and owing to the size of the dies, pressed steel covers are likely to be expensive. It has yet to be seen whether pressed steel withstands rust satisfactorily, and in any case, as frequent revision of the specification is recommended, the suggested amendment to this clause might well stand over. A thoroughly satisfactory covering material applicable to all types of meters has yet to be produced.

Clause 5.—Presumably the customer may have the meters painted how he likes, provided always that the cost of any extra work is included in the price paid for the meters.

Clause 6.—In its present form this clause possesses no

Mr. Ratcliff. practical value. Terminal boxes are as a rule the worst feature of many meters, particularly so in the case of those of Continental origin. The current-carrying capacity of the terminals and connections is apparently worked out to the fourth decimal place, but with an absolute disregard of mechanical requirements and considerations of safety. Much detail requires to be specified in order to obtain satisfactory terminal boxes. The author's suggestions are in accordance with sound practice, but I would recommend that in all sizes above 100 amperes sweating lugs should be provided for the reception of the cables, and that in the case of 500-ampere and larger sizes suitable set screws be provided in the lugs for gripping the cables in addition to the solder.

Clause 7.—The value of the manufacturer's seal is questionable.

Clause 8.—Not always convenient.

Clause 9. *Sub-section* 6.—This requirement is unnecessary and not always possible. It also does away with the advantage of adjustment by means of change wheels giving different constants.

Clause 10.—The requirements of this clause are altogether unreasonable and impracticable. The author's suggestion for the use of rivets is good, and I am pleased to note that he considers the size of plate to be too small. Not only is it too small, but it is also too thin, as these flimsy plates rot away in a very short time. Extensive experience has shown that the most satisfactory plates are those made of cast brass.

Clause 11.—This apparently allows the use of cyclometer counters, which are notoriously unreliable. The author's suggestion is very sound and reasonable, but I would go further and suggest that the old fashion clock-dials are the only ones worth serious consideration. Difficulty of reading is no valid objection to their use, since a person incapable of reading them correctly has no business to be reading electricity meters.

Clause 12.—It is a very debatable point as to what should be provided in the way of registering and testing dials, and requirements must necessarily vary somewhat, depending upon the size of the meters, or as the author calls it "the kilowatt-hour per hour capacity." (Why not kilowatt capacity?) The testing dial on a 200-kw. meter appears to be quite unnecessary, and in fact the unit-per-division dial is of doubtful utility on meters above 100-kw. capacity, unless provided purely for testing purposes.

Clause 14.—The permissible speed is rather on the high side. A speed of 100 revs. per min. for continuous-current and 50 revs. per min. for alternating-current meters is not an unreasonable restriction.

Clause 15.—A maximum permissible temperature rise might be specified.

Clause 16.—I fully agree with the author's suggested amendments. The 15-watt loss is very high, whereas his figures show only a 10-watt loss, which is more in accordance with the requirements of at least one well-known specification. A maximum pressure drop of 0·5 volt will probably be found sufficient in the case of all high-grade ampere-hour meters; watt-hour meters of small capacity appear to require a pressure drop comparable with that obtained in electrolytic meters.

Clause 17.—I agree with the author that the permissible shunt loss is far too high. Reasonable values would Mr. Ratcliff. probably be two watts per 100 volts for continuous-current meters, and one watt per 100 volts for alternating-current meters.

Clause 18.—This might be modified with advantage. In its present form it appears to necessitate the use of one specialized piece of apparatus.

Clause 20.—The author's criticism is well merited, but I cannot quite agree with him regarding the request for accuracy at low loads below $\frac{1}{2}$ ampere. Experience has shown that $2\frac{1}{2}$-ampere-hour meters when new can be made correct within $3\frac{1}{2}$ per cent at one-tenth load, and 5 per cent at one-twentieth load; and it is therefore reasonable to specify such a maximum limit of error, particularly as these small meters are only used for a not very remunerative class of consumer. The importance of high initial accuracy cannot be over-estimated, as the error is bound to increase with time, and therefore the less serious will it be if the original permissible limits have been close. It is very unfortunate in this respect that the Board of Trade have recently extended the limits of permissible error, and as a result many inferior meters will now satisfactorily pass the test requirements.

Clause 23.—The test specified is designated "Short-circuit Test." Thirty times full load is a very good momentary overload test for a meter, but it is certainly not a short-circuit test, and must not for a moment be confused with what is a really severe test which very few meters can successfully withstand.

I agree with the author that Clauses 25, 26, and 27 are rather vague, but I hardly consider that his proposed amendment much improves matters. Undoubtedly the errors under consideration are those in respect of such variations, and are not to be confused with errors existing under conditions other than those arising from the variations in question. Probably instead of the words "an error" the expression "a change in the rate of registration" would be more suitable.

Variations of wave-form.—This is only of importance in the case of meters of the induction type. The percentage departure from a true sine wave is not very definite, since it is the amplitude and frequency of the predominating harmonic which affects the accuracy of the meters. If possible, therefore, a knowledge of the most pronounced harmonic is essential, and also an approximate value for its maximum percentage amplitude. The effect of the third harmonic, for instance, can be roughly ascertained by testing the meter on a circuit of three times the normal frequency, afterwards making allowance for the amplitude of such harmonic when superimposed on the fundamental sine wave. The incompleteness of the specification appears to have been realized at the last moment, hence the footnote referring to the Appendix, which has not yet appeared, although intended to deal with some of the most technical features covered by the specification.

Mr. M. OSBORNE (*communicated*): Mr. Ratcliffe has Mr. Osborne. pointed out that the errors in electricity meters are continually increasing: the chief factor of the errors, in my opinion, is due to the "sapphire jewel bearings" wearing, after being in use a comparatively short time. I mean by this that the originally high polish of the sapphire becomes rough, which of course sets up friction. The bearing troubles form the most serious faults to which modern

Mr. Osborne. meters are liable, and the only way to obviate these troubles is by the adoption of diamonds for jewel bearings. Mr. Chattock suggested that the meter manufacturers should give a five years' guarantee with their meters. This, I contend, would only be possible by the substitution of diamonds for sapphires as the jewel bearings, because the polished surface of the sapphire wears much more than many supply engineers realize, and after two or three years in service the polish becomes somewhat rough; under this condition one cannot expect the same degree of accuracy as when the meter was first installed. Moreover, as this roughness grows gradually, it must mean a considerable loss of revenue to the electricity supply authority. The diamond after being in use for at least seven to ten years will give, owing to its much harder qualities, the same degree of accuracy as initially. Whilst admitting that the use of diamonds would add to the cost of the meters, I have made some inquiries of a Birmingham firm of jewel makers, and find that the extra cost would be comparatively small compared with the advantages gained. I am sure the results would justify the change, for in addition to the sustained accuracy of the diamond, the repairs necessary with the sapphire are eliminated, and a substantial reduction in the maintenance of the jewels is obtained. I suggest that the substitution of diamonds for sapphires for jewel bearings in electricity meters be embodied in the new British Standard Specification.

Mr. Young. Mr. A. P. Young (*communicated*): I think it is generally admitted that the British Standard Specification No. 37, published in 1907, inadequately serves the purposes for which it was presumably compiled, due chiefly to the fact that in its present form it is not applicable to some of the numerous types of meters now used for the metering of energy. The author is therefore doing a service in bringing forward this paper with a view to stimulating a general discussion of the whole question, and thereby urging the Engineering Standards Committee to prepare a revised specification. The proposed method of modifying the specification clause by clause as outlined in his paper does not, however, seem to meet the requirements of the case exactly. In the first place I would suggest that two specifications be prepared, one for continuous-current meters, and the other for alternating-current meters. This seems very desirable in view of the fact that the various types of meters for the two classes of service are of entirely different construction, with the result that their general characteristics are also different. In addition, each specification should be divided into sections, so that meters belonging to any particular class can be treated separately. That is, it might be found advisable to divide the continuous-current specification into two parts, the first dealing with the ampere-hour type of meters, and the second with the watt-hour type of meters. In the case of the specification for alternating-current meters, single-phase meters should be treated separately from polyphase meters, and then there should be a further section relating to meters operating in conjunction with current transformers. Also in each case it seems necessary that some distinction should be made between meters of the house-service type and those designed for switchboard work. With reference to the author's suggested modifications of the various clauses in the specifications I should like to make the further comments.

Clause 6.—The author proposes to standardize certain sizes of holes in the terminals for the various standard Mr. Young. sizes of meters suggested under Clause 2. This does not appear to me to be a workable arrangement, for some of the sizes given are not standard drill sizes, and it is difficult to understand how he would propose to drill the holes in the terminals. Further, I should like to know whether the author seriously puts forward the suggestion that, for the high-capacity meters referred to, it makes a satisfactory arrangement to connect the incoming cables in terminal holes by means of two clamping screws, as implied by the proposed clause. I think it is a fact that most manufacturers of repute supply cable thimbles, into which the cables are sweated for meters above 50-ampere capacity.

Clause 12.—The suggestion to use the expression "kilowatt-hour" in place of the word "unit" is, I think, not a good one. The expression "kilowatt-hour" is far too cumbersome for ordinary everyday use, and further, consumers have become so accustomed to the word "unit" that any such change as proposed by the author would certainly not meet with the approval of station engineers and meter users generally. It is quite true, however, that in other parts of the world the word "unit" as applied to electricity meters may not convey any definite idea, and as much has been heard of late regarding the use of the word "Kelvin" for the unit of electrical energy—that is, one kilowatt-hour —it would seem advisable for this aspect of the question to be considered when the specification is revised, assuming that this is eventually done.

Clause 17.—The suggestion that the consumption in the pressure circuit of a continuous-current meter for voltages up to 650 should not exceed 7 watts is to be deprecated, as I think it is generally recognized that a reliable watt-hour meter of the motor type operating on the Thomson principle cannot be constructed with such a low watt loss.

The author appears to have discreetly avoided the whole question of polyphase meters, which really stand in a class by themselves, and also that broad class comprising both single-phase and polyphase meters operating in conjunction with potential and current transformers. Leaving out the question of transformers for the time being, and considering only the question of polyphase meters, a specification dealing with these, to be complete, should standardize some system of connection. The National Physical Laboratory some two years ago, as a result of tests which they had carried out on various makes of polyphase meters, proposed a system which I believe has been adopted by most manufacturers in this country. Put briefly, the system is simply this: That considering the two phases to which the two meter elements are connected, then the arrangement must be such that the top element is inserted in the "leading" phase and the bottom element in the "lagging" phase. This seems to meet the conditions satisfactorily; but I should not only like to see some such standardization as this, but also some clear and definite explanation as to what is meant by "leading" phase and "lagging" phase respectively, as the average engineer appears to be quite ignorant on this point.

Coming to the question of meters operated in conjunction with current transformers, it does not seem to be generally recognized that in cases of this kind the governing factors, from the points of view of accuracy, are the accuracy characteristics of the transformer, as in the nature of things a meter can be constructed with a greater degree

Young. of accuracy than a current transformer. In view of this, the suggestion already put forward that there should be a distinct section in the specification relating to meters operating in conjunction with current transformers seems almost necessary. The present specification makes no mention whatever of current transformers, and one can only assume that the Committee, when they drafted the specification, did not have cases of this kind in mind. It is well known that any form of induction meter, after calibration in the ordinary way, will give different results when used in conjunction with any form of current transformer, due to the fact that the ratio is not constant but slightly dependent on the load, and further because there is a very small phase angle between the primary and secondary currents which increases as the load decreases. As a matter of interest I should very much like to know if the author would be willing to accept Clause 27, relating to the error produced on varying power factor, for the case of a meter operating in conjunction with a current transformer for all loads from full-load down to one-twentieth of full-load, as is implied. Presumably the high-capacity meters referred to under Clause 2—that is, say from 200 to 500 amperes—would have to be supplied with current transformers, so apparently the author intends Clause 27 to apply to such cases. In cases where we have polyphase meters working in conjunction with current transformers, the proposition is more difficult because on a power factor of unity there is a phase displacement of 30 degrees between the current and potential in the case of each element, so that with a power factor of 0·5 this phase displacement of one element will have increased to 90 degrees. I admit that the whole question of current transformers is very complicated, but it certainly should be confronted by any Committee formed to revise the present standard specification, with a view to removing the present uncertainties that exist. An additional complication arises from the fact that the characteristics of any transformer are dependent upon the secondary load, and as in actual practice it is usual to connect instruments, trip coils, etc., in series with the meter, it is essential that the actual operating conditions should be taken into account when the meter is calibrated by the manufacturer.

The question of potential transformers is relatively simple, as these always work at a practically constant load, and they can be designed to give quite a definite ratio at this load, with a phase displacement between the primary and secondary voltages that is for all practical purposes negligible. In conclusion, I thoroughly agree with the last portion of the author's paper in which he suggests that the Institution should urge the Engineering Standards Committee to publish as soon as possible a revised and complete specification, and it would certainly be a great improvement if the price were reduced to 1s. per copy so as to induce a wider circular and more general use both by meter manufacturers, supply station engineers, and meter users generally. Should this task be undertaken, however, it is very necessary that every phase of the problem be taken into consideration with a view to producing a specification, or specifications, which apply to every possible case likely to be met with. This, in my opinion, can only be done by dividing and sub-dividing the specification in the manner indicated above, and considering each section by itself thoroughly and completely.

Mr. E. GARTON (*communicated*): Before discussing the various clauses mentioned in Mr. Holden's paper, I should like to ask if the standard specification is to be applied to house-service meters only, or whether switchboard meters are to be included. Assuming it is only to apply to the former, I would suggest that the specification be divided into two main sections, (*a*) for continuous current, (*b*) for alternating current, and again sub-divided for various types of meters, the continuous-current section being divided into ampere-hour meters and watt-hour meters, and the alternating-current section into single-phase and polyphase meters, and a third section for meters belonging to the latter classes when used with current transformers. I think this is very necessary since it is impossible to make one specification satisfactorily cover all types. In Clause 2 the author mentions meters of higher capacity than would ordinarily be used without current transformers; these in my opinion should not appear in this clause unless it is made quite clear that they are to be used in conjunction with current transformers, but I would much prefer to see them under another clause as already mentioned. This also affects Clause 20, in which it is stated that alternating-current meters can easily be made within 2 per cent from one-twentieth full load to full load. This accuracy although easily obtained for meters without current transformers is very hard to obtain for a combination of meter and transformer, as it is impossible to construct a current transformer having the same ratio at all loads between the limits specified. Mr. Garton.

In Clause 10 reference is made to a purchaser's label, and it is mentioned that the manufacturer shall provide two holes in a suitable position for this label. Does the author intend that all meter covers should be supplied with these holes drilled? If so, I cannot agree with him, as it would necessitate undertakings not using labels plugging up these holes. It is also undesirable to ship meters with holes in the case, owing to the liability of dust entering I quite agree, however, that the purchaser's label should be standardized, but the party who drills the holes should most certainly fix the labels.

In Clause 3 the author lays down a hard-and-fast rule that the cases should be made of cast iron or pressed steel. I cannot agree that these materials are desirable for covers, which I take it are included under this heading, as they are very liable to rust, especially in coast towns and those very humid climates of the tropics. I think it would be much better to make covers of some non-corrosible metal, such as gun-metal, zinc, or aluminium, and it is immaterial whether they are cast or pressed, as the strength of a cover is purely a question of design. Personally, I should much prefer a fairly thin pressed cover, owing to the fact that meters are sometimes dropped after they have been finally tested. Should the case be robust the effect of the fall will not be apparent, whereas with a fairly thin pressed cover it will most likely become dented or damaged in such a way that it can easily be detected, and the meter will be examined to see whether it is damaged internally, whereas the meter with the more robust cover will probably be connected in circuit on the assumption that the meter is in every respect satisfactory; I think everybody must agree that a meter should be thoroughly overhauled after it has had a fall. Another disadvantage of the cast or pressed steel cover is that it affects the

Mr. Garton. accuracy of the meter, and it is quite impossible to calibrate a meter without its cover. I have heard it said that a percentage allowance to compensate for the effect of the cover can easily be made, but this is impossible owing to the fact that the error is dependent upon the position of the magnet, and this is changed when calibrating the meter. Referring again to Clause 20, I should like to know why the author considers an alternating-current meter should have a better guarantee than a continuous-current meter. With regard to the variation of wave-form, I note that the author considers a variation of wave-form of 10 per cent from the true sine curve at any point should not increase the error of the meter by more than 1 per cent. I think this is very indefinite, owing to the difficulty of determining what is meant by a 10 per cent variation in wave-form. For instance, it might be peaked to the extent of 10 per cent, or it might have a 10 per cent dip in the top of the wave. In fact one might have a very great variety of waves each having a different effect on the accuracy of the meter, but still within the variation at any point as laid down by the author. I should be very glad if the author would give a little more information on this point, and explain just how he intends to define the 10 per cent change.

Mr. Turner. Mr. H. C. TURNER (*communicated*): Whilst thoroughly agreeing that a standard specification for electric supply meters will be a splendid thing for manufacturers, electric supply authorities, and consumers generally, if universally adopted and enforced, I should like to make one or two suggestions and criticisms of the author's paper. In the first place mere statements such as are found in Clause 2, that the 2½-ampere size is preferable to the 3-ampere size, and in Clause 6, that cases of soft metal or steel jointed together are not used in the best meters, give the impression that the author has a special meter in his mind to suit which he wishes to model the specification, and that wherever the said meter is well within the specified limits or characteristics he desires to cut away the fringes in order to make the specification a closer fit to his meter. This seems also very apparent in his comments under Clause 16 *re* losses and pressure drop.

Clause 2.—The author advances no reason whatever for asserting that the 2½-ampere size is better than the 3-ampere size, but to my mind it seems that it depends largely upon whether the full load is 2½ or 3 amperes, though from a manufacturer's point of view if a 25-ampere size is made, then the 2½-ampere size will be very convenient, because then the same gears will be available for both. The author then suggests the addition of some extra sizes which are called for to some extent, but entirely overlooks the fact that from the point of view of demand there is a much larger sale for a 1½-ampere meter, and also for a size intermediate between 10 and 25 amperes, nor does he state why he deems the 75-ampere size not really necessary; this, again, I think depends on the capacity of the load. I have already commented on his statement *re* Clause 3 that the highest-class meters do not possess soft metal or jointed covers, and whilst I personally agree that cast iron is unequalled for this purpose, I should like to ask how does the author set his criterion of the highest-grade meter.

Clause 6.—The author's suggestion, while probably amenable to reason from the user's point of view, would mean an extensive and expensive stock for the manufacturer. Surely the same size of terminal (0·32 in. if the author wishes) can be used for all sizes up to 25 amperes rather than a separate size for each? Also one size for 50, 75, and 100 amperes, and then again 0·8 in. probably for 150, 200, and 300 amperes. Mr. Turner.

With Clauses 10 and 11 and the author's comments I entirely agree, but in the case of Clause 12 I consider again that the author is making a rigorous attempt to specify one special meter. The original clause is quite ample in saying that "Any testing dials shall be differently marked from the units registration dials." The number of testing dials and the point at which to change their number are surely quite arbitrary, and need only concern the tester who has to use them.

In Clause 16 the author reveals himself as a manufacturer in that he would word the specification to coincide with what the factor is able to do rather than with what the consumer or buyer would like to demand of the meters he purchases. Thus, taking a meter for a 200-volt circuit, as at present worded the meter would use up 1 per cent of the full power which it can carry, no matter what its capacity may be; whereas the author suggests that in a 2½-ampere size at 200 volts the meter should be allowed to dissipate 0·375 per cent, but in a 100-ampere size only 0·05 per cent. Now, dealing in percentages only, and considering the buyer to be a practical man of no great electrical attainments, are there any grounds for assuring him that he is doing well in allowing one meter 0·375 per cent and the other 0·05 per cent? Obviously he will say, "Make them all 0·05 per cent, please," so I opine that the specification is well worded in fixing the worst condition for one as the worst condition for all and then letting the manufacturers compete for improvements and refinements on this particular basis. For it does not always follow that meter losses are absolute losses, seeing that a meter with a slightly higher loss may through that extra energy be so designed as to give a torque of such a value that it will amply repay for those losses in the return of revenue for small long-hour loads, which a meter of low losses and low torque would not record at all. The same line of argument holds good in regard to the suggestion for the alteration of Clause 17. How could a non-technical man be persuaded that he should allow greater losses in the pressure coil of a continuous-current meter than in that of an alternating-current meter; to him both are meters, and he cannot see why one should be allowed more grace than another, though we know that it is much easier in the one case than in the other to obtain these small values of watts lost. Here again I contend that the specification should state a reasonably low figure for all, and then let individual design and merit improve on this figure in the way of competition between meter and meter.

Clause 20.—The author appears anxious to narrow the limits much more, but in doing so why should he stop, seeing that several makes of alternating-current meters can be made accurate within 2 per cent between one-fortieth of full-load and 25 per cent overload? Also, seeing that alternating-current meters can be designed so that a change of temperature up or down of 18 degrees F. does not produce an error of 1 per cent, why not exact this from all meters? Certainly in some cases it would redound to the consumer's benefit, seeing that a very common type of meter, namely the mercury motor type, has a considerable

temperature coefficient and if installed in a living room would be subjected to such changes of temperature in the winter as would render it inadmissible in Clause 20 of the specification. Of course I am well aware that many of these meters are now compensated, but I think it is safe to say that the majority are not. Nor can I bring myself to agree with the author's allegation of absurdity respecting Clauses 25, 26, and 27, though I quite concur in the matter of the altered phraseology. Using the example given, a meter may be 2 per cent slow at normal voltage; and assuming that 10 per cent variation of pressure would make the meter correct, that is would produce a 2 per cent error, then it must be remembered that by the specification meters would also have been passed which were 2 per cent fast, and that there is as much chance of these being out on circuit as there is of the slow meters, so that under the same conditions of change all these fast meters would become 4 per cent fast, whereas if the specification had been enforced this error could not have exceeded 3 per cent. For myself I should like to see inserted in the specification a limit of error for combinations of the above variations, thus—that the increase of error shall not exceed 2 per cent when with a power factor of 0·5 the normal frequency is varied 10 per cent up or down. This is a condition which is rarely fulfilled and which would well do with attention from the manufacturers.

Variation of wave-form is the subject of the next suggestion. Here the author would specify that a variation of 10 per cent from a true sine wave at any one point shall not increase the error of the meter by more than 1 per cent. I need hardly point out that a wave-form not varying more than 10 per cent at any one point might easily produce a greater error than that mentioned, whereas a wave-form varying much more than 10 per cent might likewise easily produce an error so small that it could not be computed; so that although the author's suggestion is one way of labelling wave-forms, it is not one which entirely suits the case. For myself, and as a result of many experiments, I believe that it is sufficient to specify that a meter shall have a small variation of its constant with large variations of frequency, which is quite compatible with reason, seeing that all variations of wave-form are due to the super-position of sine waves of different frequencies, generally being harmonics of the fundamental curve. On the whole it seems wiser to attack the problem from its origin, namely, variation of frequency, rather than deal with wave-forms which are of such an elusive and variable nature, so hard to define, and so numerous in kind, that there are scarcely any two alike. Again is it not a fact that the wave-form of the pressure circuit is quite distinct from that of the series circuit by virtue of the different inductions therein? None the less, if the latest innovations of polycyclic systems are continued, it will be necessary for the manufacturers to attack this problem in real earnest. I agree with the author that the specification might easily be made to embrace polyphase meters and also prepayment and two-rate meters, and I strongly support the author's suggestion that the Institution should urge the Engineering Standards Committee to publish as soon as possible a revised and complete Standard Specification for Electric Supply Meters.

Mr. Holden. Mr. S. H. HOLDEN (*in reply*): As several speakers have referred to the same points, perhaps I may be allowed to make my reply general and not refer specifically to individual speakers.

In the first place, with I think one exception, speakers confined themselves to a purely insular view of the subject, ignoring the advantage to British trade with foreign countries which would arise from the acceptance of a standard specification by English engineers in England and the prestige which it would thus acquire in many colonies and foreign countries. Without giving any advantage to one English manufacturer over another, English engineers should be willing to assist English manufacturers to compete in the world's markets.

Cases.—Several engineers specify a cast-iron case and nothing else: to such engineers the present Standard Specification is insufficient, and to make it acceptable to them I propose specifying the material, viz. cast iron or pressed steel. There is nothing to prevent anyone buying a cheaper form of case if desired. It is well understood that meters with iron covers must be tested with the covers on. Several speakers suggested limits of accuracy different from mine. The great thing is to have the limits simple. The suggestion of 0·25 ampere for the lower limit instead of my proposed 0·5 ampere should be accepted; and 2 per cent instead of the present $2\frac{1}{2}$ per cent is also a good suggestion.

Holes in terminals.—The suggestion for sizes of holes for cables in terminals should be supplemented by a statement that all meters above 250-ampere capacity should have sockets into which the cables can be soldered. It is hoped that those speakers who disapproved of the proposed sizes will state the sizes they consider suitable.

Standard sizes.—The 300-ampere size might well be omitted. If larger sizes than 500 amperes should be specified, I would suggest 750- and 1,000-ampere.

Pressure drop.—Plenty of good meters can be obtained within the limits I suggest. It would be unwise to lower the standard for the sake of one or two makers who use a much larger pressure drop. The limits suggested were not intended to apply to meters with separate shunts, *i.e.* switchboard meters. If these are to be included, some modification would no doubt be necessary.

Loss in pressure circuit.—I do not at all agree to specifying this at 2 watts per 100 volts. Good alternating-current meters take only 2 watts at 500 volts single-phase, or 4 watts polyphase; and continuous-current meters are made at 7 watts for the same voltage. If the Standard Specification called for 4 watts at 500 volts, makers would soon meet that requirement.

Labels.—The suggestion that the customer's label should be settled individually is not good. The main object of the specification is to leave nothing to be settled, outside it. Let there be a standard size of label and standard drilling to fix it. The only thing then to be settled would be drilling or no drilling.

Large alternating-current meters.—All guarantees of accuracy should assume that the meter-maker also supplies the transformers, and that errors in the transformation ratio are counted as part of the meter error.

Wave-form.—As long as engineers refer to the effect of variation some limit must be fixed; any improvement on that proposed would be useful.

Temperature.—The permissible variation in speed due to temperature should be fixed, and the declaration of its

Mr. Holden. amount would not then be necessary on the label. Mercury motor meters at present suffer from a disadvantage in this respect, but I do not consider that the Standard Specification should be framed in such a way as to relieve manufacturers of the necessity of striving after improvement.

Insulation.—The suggestion for a more severe test with alternating current is certainly good. Meters at present offer plenty of scope for improvement.

Guarantee.—Many managers of meter departments at present overhaul their meters after two or three years' service. Obviously no guarantee should extend beyond this overhaul.

Counters.—The best types of springing-figure counters leave no possibility of an error of 10 units as described. The specifications should exclude any type that has this possibility of error.

Dial marking.—"Kilowatt-hour" is well understood on the Continent and in most foreign countries. "Board of Trade unit" is not; and I believe the Board of Trade themselves object to its use upon meter dials. The term "unit" is meaningless by itself.

Clock-type meters.—I have no experience with these, so am not competent to make any suggestions. If there are special points in regard to them that require specification a suitable clause should be inserted.

External fields.—The effect of these is important, and a Mr. Holden. clause defining what strength of stray field may or must not affect a meter, and to what extent, might be useful. I entirely disagree with the speaker who stated that every form of meter could be influenced to the extent of 5 or 6 per cent by stray fields. Such a meter would be a very inferior article.

Polyphase meters.—These should have the same limits of errror as single-phase meters. The suggestion of a standard arrangement of terminals is most important, and, indeed, this applies to every type of meter. Why should one maker place his + terminal on the right-hand side and another maker place his on the left? And why should some terminals be at the top, others at the sides, and others at the bottom? It is to be hoped that the suggestion to include polyphase meters in the specification and to impose standard conditions of testing will be accepted by the Engineering Standards Committee.

It is understood that all tests are made in well-equipped test-rooms or laboratories and not on site. Electrolytic meters are excluded by the title of the present Standard Specification, as also are meters of the switchboard type and many other forms of meters. It might be well in the future to divide the Standard Specification into sections, each dealing with a distinct type of meter, and alter the title accordingly.

THE MAGNETIZATION OF IRON AT LOW INDUCTIONS.

By LANCELOT W. WILD, Member.

(*Paper first received 14th August, and in final form 29th October, 1913.*)

Although the magnetization of iron at flux densities varying from 1,000 to 20,000 has been very thoroughly investigated, experimenters have hitherto generally fought shy of carrying out investigations at very much lower flux densities.* It has therefore occurred to the author that an investigation between $B = 1$ and $B = 100$ would not be wholly without interest. Tests have been carried out accordingly on two samples of transformer steel having widely different characteristics. These are known as Lohys (mild steel) and Stalloy (silicon steel) respectively.

The samples were in the form of strips measuring 7 in. × 1 in. (17·78 × 2·54 cm.) and were built up into magnetic squares of the form shown in Fig. 1, alternate layers being arranged so as to break joint. The squares were built up in fibre bobbins permanently fixed to a base-board. These bobbins were evenly wound with 220 turns of No. 14, 220 turns of No. 20, and 4,400 turns of No. 28 double-cotton-covered copper wire. This last winding was divided into 4 equal sections, which could be arranged in series or parallel, so that all 4 sides of the square were equally loaded.

All the above windings were used as secondaries. In addition a primary winding was put on consisting of 4 turns only, one turn being on each side of the square. The leads from the primary winding were twisted together and led away to a reversing switch at a considerable distance.

The board on which the coils were fixed was placed on a plush mat and was so tilted as to ensure that the earth's field should pass through the square at right angles to the plane of magnetization.

Tests were made with both continuous and alternating current. For the continuous-current tests a ballistic galvanometer having a 12-second period was employed, the magnetizing current being reversed by a switch in the usual manner. A 2-way switch was introduced into the secondary circuit so that the galvanometer could be isolated from the windings whilst being short-circuited on itself. The secondary windings were thus never short-circuited, and the introduction of artificial viscosity was avoided.

The alternating-current tests were made with an ammeter in the primary circuit to measure H, and B was measured with a combination of rectifier and calibrated galvanometer taking current from the secondary circuit. An adjustable mutual inductance was also included for the purpose of measuring the phase angle and the losses.

* The field has to a certain extent been explored by Wilson, Gumlich, Kummer, and Fromme (see Bibliography, p. 105).

The arrangement of circuits for carrying out the alternating-current tests is shown in Fig. 2. I represents the magnetic square, wound with primary P and secondary S W. In series with P there is the primary winding of the adjustable mutual inductance M, the ammeter A, and adjustable resistance R. C represents a rectifying commutator run by a synchronous motor. One pair of brushes

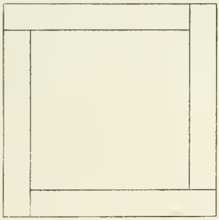

FIG. 1.

from this is connected to the galvanometer G through an adjustable resistance. G can be calibrated in volts and its constant varied by altering the resistance in series with it. It is in fact a voltmeter having a very large number of ranges and taking only a very small current. S is a 3-way switch connected so as to short-circuit the rectifier on itself, secondly to include the secondary winding of the

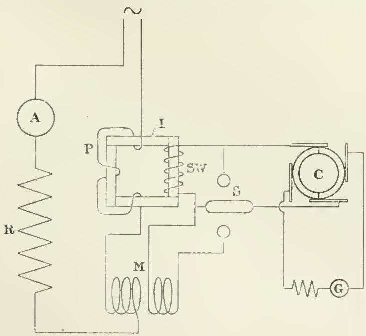

FIG. 2.

magnetic square, and thirdly to include also the secondary of the mutual inductance, the E.M.F. from which should be very nearly in opposition to the E.M.F. in the secondary of the magnetic square.

Neglecting for the moment the effect of thermal E.M.F.'s, the method adopted was as follows :—

S was placed on the middle stud, the rectifier brushes were rocked into the position which gave the maximum reading on G, and the primary current was then adjusted until the desired reading was obtained on G.

Assuming that the primary current is a perfect sine wave, $\mathbf{H}_{\max.}$ can be calculated from the formula—

$$\mathbf{H} = \frac{0{\cdot}4\,\pi\,T\,I\,.\,\sqrt{2}}{l},$$

where T I is the number of ampere-turns and l is the length of the magnetic circuit in centimetres. $\mathbf{B}_{\max.}$ may be calculated from the formula—

$$\mathbf{B}_{\max.} = \frac{V \times 10}{4\,f\,A\,.\,T},$$

where V is the rectified voltage, f is the periodicity, A is the area of the iron, and T is the number of secondary turns.

Having obtained these readings, S was next placed on the bottom stud and M was adjusted until G read zero. S was then returned to the middle contact and the rectifier brushes were rocked round until G again read zero. S was

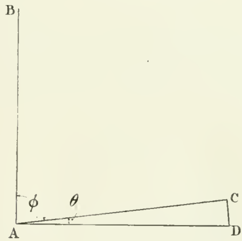

FIG. 3.

then put again on the bottom contact and the galvanometer reading was taken.

This last reading divided by the first equals cos ϕ. This again multiplied by the number of primary ampere-turns gives the loss in terms of ampere-turns. This again multiplied by the rectified volts per turn and the form factor gives the loss in watts.

In rectifying very small voltages the author has found it necessary to employ a very considerable pressure between the brushes and the commutator. The whole rectifier consequently gets very hot and thermal electromotive forces are developed. It was therefore found necessary to work to a false zero when taking the lower readings. This was obtained by turning the switch on to the top contact, when the rectifier was short-circuited upon itself. This had to be done at each stage as the thermal E.M.F. was continually changing.

Referring now to Fig. 3, let A B represent the current in amperes, A C the voltage in the secondary of the magnetic square, and A D the voltage in the secondary of the mutual inductance. Then C D divided by A C equals tan θ; if θ is small this is practically equal to sin θ. Now sin θ equals cos ϕ; therefore C D divided by A C equals cos ϕ.

Another way of representing the idea is as follows :—

The secondary voltage from the magnetic square may provisionally be considered to be a sine wave, and is commutated at zero. The mutual-inductance secondary voltage is a sine wave nearly in opposition to the first wave, and may be resolved into two components, one equal to and in phase with the first wave, and a second component of small magnitude in quadrature. When the brushes are shifted through 90 degrees, the quadrature component commutates at zero and is the only one to cause a unidirectional current to flow through the galvanometer.

So far sine waves have been assumed throughout. The case is, however, a little more complicated.

The alternator employed gives an almost perfect sine wave of electromotive force at small loads. The re-active voltage of the magnetic square was too small to affect the current wave. The calculation of $\mathbf{H}_{max.}$ may therefore be taken as correct so far as wave form affects it. The formula for calculating $\mathbf{B}_{max.}$ is independent of wave form. With a sine current-wave the mutual-inductance electromotive force will also be a true sine, although any very small harmonic in the current will be exaggerated in the E.M.F. wave.

At very low inductions, when the permeability assumes a constant value, the secondary voltage of the magnetic square should be nearly a sine wave. At the higher inductions, however, $\mathbf{B}$ not varying proportionally with $\mathbf{H}$, the flux wave should be peaked and the E.M.F. wave should be flat-topped.

With the secondary of the magnetic square connected approximately in opposition to the secondary of the mutual inductance, we have the following :—

A. The fundamental wave produced in the transformer winding.

B. Harmonics in phase* with A, also produced in the transformer winding.

C. A component from the mutual inductance, exactly neutralizing A.

D. A component from the mutual inductance in quadrature with A.

E. Harmonics produced in the transformer in quadrature with A.

With the switch on the middle contact the galvanometer measures the algebraic mean of A + B through a half period, that is, the mean ordinate of the fundamental + $\frac{1}{3}$ of the third harmonic, $\frac{1}{5}$ of the fifth harmonic, etc.

With the switch on the bottom contact and the brushes of the rectifier shifted through 90 degrees, the galvanometer measures the algebraic mean through a half period of D + E, that is, the mean ordinate of D + $\frac{1}{3}$ of the third harmonic, $\frac{1}{5}$ of the fifth harmonic, etc.

A wattmeter would have taken account of D only, consequently the power-factor reading obtained is in error by an amount depending upon the magnitude of E.

By rocking round the brushes in small regular steps when the switch was on the middle contact the ordinates of the flux wave could be obtained. This was done for $\mathbf{B}_{max.} = 100$ in the case of Stalloy and Lohys. No trace of quadrature harmonics could be detected, indicating that the method of test should give the same results as would have been obtained by a wattmeter. Further, a wattmeter test was actually carried out on Stalloy at $\mathbf{B}_{max.} = 100$ at 50 periods, and the result was in agreement within 1 per cent of the result obtained by the rectifier method.

From the flux wave plotted for $\mathbf{B}_{max.} = 100$ the form factor of the E.M.F. wave was calculated and came to 1·09 for both samples, showing the wave to be flat-topped, as already stated. A small error is introduced by employing a galvanometer consuming power. At $\mathbf{B}_{max.} = 1$ the power consumed was about 2 per cent of the measured loss in the iron. At higher flux densities the galvanometer took considerably less than this proportion.

The general data concerning the samples will be found in Table A.

TABLE A.

	Lohys	Stalloy
No. of strips ...	204	192
Weight in lb. ...	5·57	5·39
Density	7·61	7·52
Thickness in inches	0·0142	0·0148
Length of stampings	7 in. (17·78 cm.)	7 in. (17·78 cm.)
Length of magnetic circuit	69 cm.	69 cm.
Area of iron ...	4·81 sq. cm.	4·71 sq. cm.
Watts per lb. at 50 periods (= ampere-turns × $\cos\phi$ × $\mathbf{B}_{max.}$)	× 0·00000192	× 0·00000195
$\mathbf{H}$ (continuous current) = ampere-turns × 0·0182		
$\mathbf{H}$ (alternating current) = ampere-turns × 0·0182 × $\sqrt{2}$		

THE AFTER-EFFECT OF DEMAGNETIZATION.

The specimens were demagnetized as follows: The squares were magnetized up to about $\mathbf{B}_{max} = 10{,}000$ at 50 periods, and the alternator field-current was gradually reduced to zero, leaving the iron, however, still subjected to a small magnetizing force, due to the residual magnetism of the alternator. The alternator was then shut down, the circuit not being interfered with until the machine had quite stopped rotating.

As soon as the alternator had stopped, the connections were made for carrying out the ballistic tests. The magnetizing current was reversed 20 times at 2-second intervals with the galvanometer isolated from the secondary. The galvanometer was then coupled to the secondary, and, 2 minutes after the alternator had stopped, the magnetizing current was reversed and the throw of the galvanometer taken. A second throw in the reverse direction was taken at 4 minutes. The average of these two was considered to be the throw at 3 minutes.

A second pair of throws were taken at 6 and 8 minutes and were averaged to obtain the throw for 7 minutes. Throws were taken after this at suitable intervals up to 72 hours. The current was reversed 20 times at 2-second intervals before each throw was taken.

The results of these tests are given in Tables B and C.

Referring to Table B, it will be observed that what may be called the ballistic permeability of Lohys falls quickly

* By the term "in phase" when applied to harmonics is meant that they are zero when the fundamental is zero and their direction is such as to raise the mean ordinate of the resultant wave.

at first and afterwards more slowly up to about 48 hours. The total fall is 5·2 per cent from $B = 2·86$, 4·0 per cent from $B = 16·1$, and 1·8 per cent from $B = 121$. From this, one might say that the fall is greatest at very low inductions and continually decreases as the induction is increased.

Table B.—Lohys.

Showing the decrease of permeability with time after demagnetization. Magnetizing force constant throughout each experiment.

Time in hours	B	μ	B	μ	B	μ
0·05	2·86	310	16·1	372	121	619
0·133	2·85	309	16·0	370	121	619
0·25	2·84	308	15·9	369	120·5	616
0·67	2·83	306	15·9	369	120·5	616
2	2·82	305	15·85	367	—	—
3	2·81	304	15·8	366	—	—
5	2·79	302	—	—	—	—
24	2·74	296	15·5	360	119·5	611
48	2·72	294	15·4	357	119	608
72	2·72	294	15·4	357	119	608
Total fall	5·2 %		4·0 %		1·8 %	

Referring now to Table C it will be observed that the fall of ballistic permeability is very much greater for Stalloy than for Lohys. The fall, moreover, takes longer to arrive at completion. The total fall observed was 20 per cent from $B = 2·88$, 25 per cent from $B = 20·6$, and 7 per cent from $B = 127$. As before there is a decrease of the fall as the induction increases, but there is also a decrease of the fall in the other direction.

Table C.—Stalloy.

Showing the decrease of permeability with time after demagnetization. Magnetizing force constant throughout each experiment.

Time in hours	B	μ	B	μ	B	μ
0·05	2·88	500	20·6	693	127	1,030
0·12	2·78	485	20·4	685	126	1,025
0·2	2·74	478	20·2	678	—	—
0·3	2·70	470	20·1	675	125	1,015
0·6	2·64	460	20·0	672	—	—
1	2·59	451	19·8	664	124	1,006
1·5	2·54	442	19·6	658	—	—
2·5	2·50	434	19·3	649	123·5	1,003
24	2·34	407	16·8	565	119	970
48	2·31	401	15·6	525	118	960
72	2·30	400	15·5	520	118	960
Total fall	20 %		25 %		7 %	

It was found that after the permeability had fallen it could again be partially restored by subjecting the iron to a sharp blow or a series of blows. For example, the Stalloy square was magnetized with a force of $H = 0·0298$; 48 hours after demagnetization the value of B obtained was 15·6. The square was then dropped 6 times on to the floor through a distance of 6 in., the magnetizing current being switched off for the time being. After 20 reversals at 2-second intervals the value of B was found to be 18·8 The iron was then demagnetized, and 3 minutes later the value of B was found to be 20·6. In this case a series of blows produced 64 per cent of the effect of demagnetization treatment.

On alternating current Stalloy behaves in much the same way. At $B_{max.} = 1$ the permeability one hour after the demagnetization treatment was found to be 392. At 48 hours it had declined to 360.

Viscosity.

The ballistic galvanometer employed had a period of 12 seconds. It thus arrived at the end of its swing in 3 seconds, and any impulse received after this period was not recorded in the throw.

The loss of throw due to the delayed impulse was approximately determined in the following manner. The magnetizing current was reversed and the throw taken in the ordinary way. Next the current was reversed with the galvanometer isolated; and 3 seconds later the galvanometer was switched in and the delayed impulse recorded. Further tests were made after 6, 9, 12, and 15 seconds. All these additional throws were added together and taken as the total loss of throw due to the delayed impulse.

The results of these tests are given in Table D. On the whole the viscosity is greater for Lohys than for Stalloy. At $B = 15$, however, Stalloy shows the larger viscosity. The viscosity loss falls off greatly at $B = 120$.

Table D.

Showing the estimated reduction of throw of the galvanometer spot on account of viscosity.

B	Lohys	Stalloy
2·7	6·0 %	3·5 %
15	3·0 %	3·7 %
120	1·0 %	0·5 %

Taking each sample separately the variation of viscosity loss is of the same order as the variation of permeability fall some time after demagnetization. It rather looks as if there might be some connection here.

The above tests were made one hour after demagnetization treatment and again after 48 hours. Although the permeability meanwhile had declined there was no difference observed in the viscosity loss.

Another peculiar effect of viscosity is that it has a greater influence upon the ballistic throws when the reversal of the magnetizing current is divided into two parts, that is, the current is broken and the throw taken and then the current is re-made in the reverse direction and the throw taken.

This is shown in Tables E and F.

Referring to Table E it will be observed that Lohys shows a difference of 1·6 per cent at $B = 2·8$, 3·9 per cent at $B = 15·9$, and 1·4 per cent at $B = 120$. It is worthy of remark that whilst the viscosity loss on reversal was

*

found to be greatest at $B = 2.8$, the difference between the throws on reversal and "break and make" was greatest at $B = 15.9$.

TABLE E.—LOHYS.

Showing the difference between the throws on first breaking the magnetizing current and then remaking it in the reverse direction, as against reversing in one operation.

	Galvanometer Throws				
B	Break	Make	Break + Make	Reverse	Difference
2·8	160·5	61·5	121·5	123·5	1·6 %
15·9	179	93	172	179	3·9 %
120	103	170	273	277	1·4 %

Referring now to Table F it may be noted that a difference as high as 8·4 per cent was actually found at $B = 20$ for Stalloy. At $B = 2.3$ the difference was only 0·5 per cent, and at $B = 118$ it was only 0·4 per cent. The

TABLE F.—STALLOY.

Showing the difference between the throws on first breaking the magnetizing current and then remaking it in the reverse direction, as against reversing in one operation.

B	Break	Make	Break + Make	Reverse	Difference
2·3	49·5	50	99·5	100	0·5 %
6·8	141·5	145	286·5	292	1·9 %
13	128	135	263	272	3·3 %
20	88·5	108·5	197	215	8·4 %
118	114·5	149·5	264	265	0·4 %

explanation of these figures is far from obvious. Previous experimenters have attempted to measure ballistically the hysteresis loss in iron. In view of these figures now tabulated it would appear that such attempts are bound to be rather abortive when measurements below $B = 100$ are essayed.

Another peculiar effect of viscosity is that it may to a certain extent be reduced by carrying out reversals at rather long intervals. The Stalloy square was subjected to a constant magnetizing force which was reversed 22 times at 2-minute intervals. The results of these tests are given in Table G.

The value of B recorded was 15·4 for the first pair of reversals. This subsequently increased quickly at first and more slowly afterwards to 16·1 for the 17th and 18th reversals, after which no further increase could be found. The tests were repeated with the specimen subjected to 20 reversals at 2-second intervals between each 2-minute interval and exactly the same throws were obtained. Evidently each successive reversal at 2-minute intervals widens the limit of magnetization, but 2-second reversals never allow the iron to attain to even the previous limit.

TABLE G.—STALLOY.

Showing the effect of carrying out repeated reversals at intervals of 2 minutes. Test carried out 48 hours after demagnetization.

Average of Reversals	B
1 and 2	15·4
3 „ 4	15·6
5 „ 6	15·75
7 „ 8	15·85
9 „ 10	15·9
11 „ 12	15·95
13 „ 14	16·0
15 „ 16	16·05
17 „ 18	16·1
19 „ 20	16·1
21 „ 22	16·1

Total rise: 4 per cent.

It appears probable that if the squares could be first subjected to demagnetization treatment and then to a magnetizing force maintained constant for several days, the value of B actually attained at the end of this time would be materially higher than would be indicated by any ballistic tests made by reversing the magnetizing current.

Probably the only way actually to measure the true continuous-current permeability would be to break the magnetic square and withdraw the ballistic coil. The author has not found this method practicable.

FLUX DENSITY AND PERMEABILITY.

Ballistic tests were made 48 hours after the demagnetization treatment and the results are given in Tables H and I.

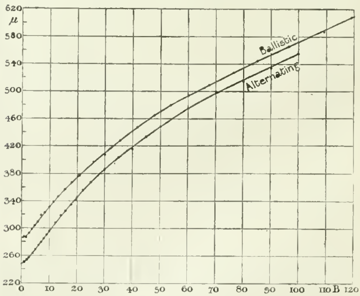

FIG. 4.—Lohys.

The tests were commenced at the lowest induction and carried upwards, the magnetizing current being reversed 20 times at 2-second intervals after each adjustment.

Alternating-current tests of permeability were also made 48 hours after the demagnetization treatment and the results obtained are given in Tables J, K, L, and M. The permeability was found to be the same for 25 and 50

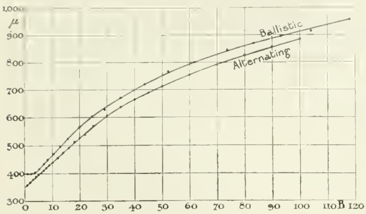

FIG. 5.—Stalloy.

periods, such small differences as were actually measured being within the range of possible experimental error.

The ballistic and alternating permeabilities have been plotted as curves in Figs. 4 and 5. Referring to Fig. 4

TABLE H.—LOHYS.

Showing the permeability obtained 48 *hours after demagnetization, the magnetizing force being reversed* 20 *times at* 2-*second intervals before each test.*

H	B	μ
0·00298	0·86	288
0·00572	1·64	287
0·00920	2·70	293
0·0124	3·70	299
0·0156	4·75	304
0·0190	5·90	310
0·0222	7·09	319
0·0260	8·40	323
0·0296	9·85	332
0·0332	11·25	339
0·0371	12·9	347
0·0431	15·4	357
0·0490	18·0	367
0·0553	20·8	377
0·0650	25·8	397
0·0735	30·0	408
0·0830	35·4	428
0·0930	41·7	449
0·103	47·8	464
0·1115	53·5	480
0·122	60·3	494
0·1325	67·6	510
0·145	76·5	527
0·156	85·0	545
0·1705	96·5	565
0·186	109·0	588
0·196	119·0	608

it will be seen that the permeability of Lohys is considerably less on alternating current, the difference decreasing as the induction increases. Stalloy on the other hand shows a great peculiarity at very low inductions. At $B = 3$ the ballistic permeability attains a constant value, but the alternating permeability continues to fall as far as $B = 1$ and possibly right to zero.

The permeabilities are further compared in Tables P and Q. With Lohys the difference is 14·3 per cent at $B = 0$, continually decreasing to 3·0 per cent at $B = 100$. With Stalloy the difference is 12·5 per cent at $B = 0$, 4·8 per cent at $B = 5$, 6·2 per cent at $B = 20$, and then continually decreases till it gets down to 2·7 per cent at $B = 100$.

There is every indication that the difference between ballistic and alternating permeability would become little or nothing at higher inductions.

From these tests it would appear that the permeability of iron can be divided into two parts, the one independent

TABLE I.—STALLOY.

Showing the permeability obtained 48 *hours after demagnetization, the magnetizing force being reversed* 20 *times at* 2-*second intervals before each test.*

H	B	μ
0·00300	1·20	400
0·00575	2·31	401
0·0092	3·71	403
0·01255	5·25	418
0·0157	6·84	435
0·0191	8·60	450
0·0225	10·60	471
0·0262	12·95	494
0·0298	15·6	525
0·0351	19·8	565
0·0406	24·4	602
0·0465	29·2	630
0·0524	35·0	670
0·0605	43·5	720
0·0680	52·0	765
0·0773	61·6	800
0·0870	73·3	845
0·0955	83·0	870
0·1035	93·0	895
0·1130	104·0	917
0·1230	118·0	960

of frequency, the other only becoming apparent when the frequency is extremely low. The case is somewhat analogous to the absorption of a condenser. At $B = 1{,}000$ and upwards the absorption flux may be said to be very small by comparison with the whole flux, but between $B = 1$ and $B = 100$ the absorption flux forms quite a large proportion of the whole.

ENERGY LOSSES.

Tables J, K, L, and M besides giving the permeability also give details of the magnetizing current, power factor, and losses at 25 and 50 periods. The eddy-current loss was determined at $B_{max.} = 10{,}000$ and 25 and 50 periods by a wattmeter test. It has been assumed that the eddy loss in ampere-turns may be taken as proportional to $B_{max.}$.

An error is no doubt introduced in the estimation of the eddy-current loss by reason of the E.M.F. wave being slightly flat-topped; the amount of this error is not quite known, but it should not exceed 2 per cent, the difference

between the form factor of a sine wave and the wave form found at $\mathbf{B}_{max.} = 100$.

The hysteresis losses have been plotted as curves in Figs. 6 and 7. The upper curve in each case covers the whole region up to $\mathbf{B}_{max.} = 100$, and the lower curve from $\mathbf{B}_{max.} = 0$ to $\mathbf{B}_{max.} = 10$. The dots represent readings at 25 periods and the crosses at 50 periods.

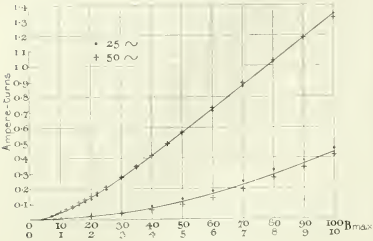

FIG. 6.—Lohys.

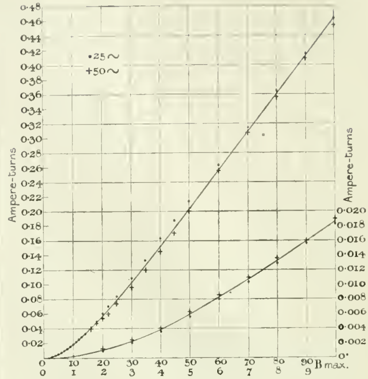

FIG. 7.—Stalloy.

TABLE J.—LOHYS.

Showing the power factor, permeability, and losses at 25 periods.

$\mathbf{B}_{max.}$	Cos ϕ	Ampere-turns				μ	Total Loss in Micro-watts per lb.
		Total	In-phase	Eddy	Hysteresis		
1	0·012	0·156	0·0019	0·0011	0·0008	249	0·0018
2	0·014	0·306	0·0043	0·0021	0·0022	253	0·0082
3	0·017	0·452	0·0077	0·0032	0·0043	257	
4	0·021	0·590	0·0124	0·0043	0·0081	263	
5	0·025	0·723	0·0181	0·0053	0·0128	269	0·087
6	0·029	0·848	0·0246	0·0064	0·0182	275	
7	0·033	0·97	0·0320	0·0075	0·0245	280	
8	0·037	1·09	0·0405	0·0085	0·032	283	
9	0·040	1·20	0·048	0·0095	0·0385	290	
10	0·043	1·31	0·0565	0·0105	0·046	296	0·54
12	0·048	1·51	0·0725	0·013	0·0595	308	
14	0·053	1·71	0·091	0·015	0·076	317	
16	0·058	1·91	0·111	0·017	0·094	324	
18	0·0635	2·08	0·135	0·019	0·116	334	
20	0·069	2·24	0·154	0·021	0·133	345	2·96
22	0·075	2·40	0·180	0·023	0·157	355	
25	0·084	2·63	0·221	0·027	0·193	368	
30	0·098	3·02	0·296	0·032	0·264	385	
35	0·112	3·37	0·378	0·037	0·341	402	
40	0·124	3·72	0·461	0·042	0·419	417	
45	0·135	4·02	0·543	0·048	0·495	432	
50	0·145	4·32	0·625	0·053	0·572	450	30·0
60	0·159	4·88	0·775	0·065	0·71	475	
70	0·172	5·45	0·94	0·075	0·865	500	
80	0·184	6·02	1·11	0·085	1·025	515	
90	0·196	6·53	1·28	0·095	1·185	535	
100	0·207	7·00	1·45	0·105	1·345	555	139

Watts per lb. = $\mathbf{B}_{max.}$ × in-phase ampere-turns × 0·00000096.

TABLE K.—LOHYS.

Showing the power factor, permeability, and losses at 50 periods.

$\mathbf{B}_{max.}$	Cos ϕ	Ampere-turns				μ	Total Loss in Micro-watts per lb.
		Total	In-phase	Eddy	Hysteresis		
1	0·015	0·155	0·0023	0·0021	0·0002	250	0·0044
2	0·020	0·305	0·0061	0·0042	0·0019	255	0·0234
3	0·0225	0·450	0·0101	0·0064	0·0037	258	
4	0·025	0·585	0·0145	0·0085	0·0060	265	
5	0·275	0·720	0·198	0·0106	0·0092	270	0·190
6	0·031	0·848	0·0263	0·0127	0·0136	275	
7	0·035	0·965	0·0338	0·0148	0·0190	281	
8	0·040	1·09	0·0436	0·0169	0·0267	285	
9	0·044	1·195	0·525	0·191	0·0334	292	
10	0·048	1·305	0·0625	0·0212	0·0413	296	1·24
12	0·056	1·50	0·084	0·254	0·0585	309	
14	0·064	1·69	0·108	0·0297	0·078	322	
16	0·072	1·90	0·137	0·034	0·103	327	
18	0·079	2·07	0·163	0 038	0·125	336	
20	0·086	2·24	0·193	0·042	0·151	345	7·42
22	0·092	2·39	0·220	0·047	0·173	357	
25	0·100	2·62	0·262	0·053	0·209	370	
30	0·1115	3·01	0·336	0·064	0·272	387	
35	0·123	3·35	0·412	0·074	0·338	405	
40	0·1345	3·71	0·500	0·085	0·415	417	
45	0·146	4·00	0·584	0·096	0·488	436	
50	0·156	4·31	0·672	0·106	0·566	450	64·5
60	0·174	4·89	0·850	0·127	0·723	475	
70	0·190	5·45	1·035	0·148	0·887	500	
80	0·201	6·01	1·21	0·169	1·04	515	
90	0 210	6·53	1·37	0·191	1·18	535	
100	0·217	7·00	1·52	0·212	1·31	555	292

Watts per lb. = $\mathbf{B}_{max.}$ × in-phase ampere-turns × 0·00000192.

There is a considerable difference at some points between the results recorded at the two periodicities. These differences are too persistent to be ascribed to errors of reading or adjustment. Either the differences are real or else between the two tests there must have been some difference of conditions. Very likely there

are conditions affecting the magnetization of iron at low densities that have not yet been suspected. One thing is clear that the differences arise from a difference of power factor rather than a difference of magnetizing current.

The losses are given in ampere-turns rather than watts, as this make clear curves possible over a long range. To obtain the results in watts, the ampere-turns require to be multiplied by the volts per turn. The conversion constants are given at the foot of the tables.

If hysteresis watts varied as the square of $\mathbf{B}_{max.}$, the ampere turns would vary proportionally to $\mathbf{B}_{max.}$ and the curves would be simple straight lines passing through

TABLE L.—STALLOY.

Showing the power factor, permeability, and losses at 25 periods.

$\mathbf{B}_{max.}$	Cos ϕ	Ampere-turns				μ	Total Loss in Micro-watts per lb.
		Total	In-phase	Eddy	Hysteresis		
1	0·0045	0·108	0·0005	0·0003	0·0002	360	0·0005
2	0·007	0·210	0·0015	0·0006	0·0009	368	0·0029
3	0·0095	0·306	0·0029	0·0009	0·0020	379	
4	0·012	0·400	0·0048	0·0012	0·0036	388	
5	0·0145	0·492	0·0071	0·0015	0·0056	394	0·0345
6	0·017	0·580	0·0099	0·00185	0·0080	401	
7	0·019	0·662	0·0125	0·00215	0·0104	410	
8	0·021	0·740	0·0155	0·0025	0·0130	420	
9	0·023	0·800	0·0185	0·0028	0·0157	436	
10	0·025	0·870	0·0215	0·0031	0·0184	446	0·21
12	0·029	1·005	0·0290	0·0037	0·0253	462	
14	0·033	1·135	0·0375	0·00435	0·0332	478	
16	0·037	1·25	0·0465	0·00495	0·0415	495	
18	0·041	1·36	0·0560	0·0056	0·0504	513	
20	0·045	1·46	0·0655	0·0062	0·0593	531	1·28
22	0·049	1·56	0·0765	0·0068	0·070	545	
25	0·054	1·70	0·092	0·00775	0·084	570	
30	0·615	1·92	0·118	0·0093	0·109	605	
35	0·0685	2·12	0·145	0·0108	0·134	640	
40	0·755	2·32	0·175	0·0124	0·163	668	
45	0·081	2·51	0·202	0·0140	0·188	693	
50	0·085	2·70	0·229	0·0155	0·214	718	11·1
60	0·092	3·06	0·282	0·0186	0·263	760	
70	0·099	3·40	0·336	0·0217	0·314	797	
80	0·1045	3·74	0·390	0·0248	0·365	830	
90	0·109	4·06	0·443	0·0279	0·415	860	
100	0·113	4·36	0·493	0·0310	0·462	890	48

Watts per lb. = $\mathbf{B}_{max.}$ × in-phase ampere-turns × 0·000000975.

the origin. A lower hysteretic index than 2 would require the curves to be convex, instead of which they are about straight from $\mathbf{B}_{max.} = 100$ down to $\mathbf{B}_{max.} = 30$, and then become concave, indicating that the hysteretic index is over 2 throughout. The hysteretic indices up to $\mathbf{B}_{max.} = 10$ have been calculated and are embodied in Tables N and O. The index is in the neighbourhood of 3 for both samples at the lower flux densities. Whether it attains any higher value below $\mathbf{B}_{max.} = 1$ has not been established.

It was considered desirable to make a comparison between ballistic and alternating-current methods of measuring hysteresis, although there was no expectation of any agreement being obtained.

If the two sides of a hysteresis loop are parallel, all the ordinates are equal, and it should only be necessary to measure the residual flux. The residual flux divided by the maximum flux, otherwise the retentiveness, may be taken as nearly corresponding to cos ϕ on alternating current. A comparison has been made on these lines.

TABLE M.—STALLOY.

Showing the power factor, permeability, and losses at 50 periods.

$\mathbf{B}_{max.}$	Cos ϕ	Ampere-turns				μ	Total Loss in Micro watts per lb.
		Total	In-phase	Eddy	Hysteresis		
1	0·0085	0·108	0·0009	0·0006	0·0003	360	0·0018
2	0·0115	0·209	0·0024	0·0012	0·0012	370	0·0094
3	0·014	0·305	0·0043	0·0019	0·0024	381	
4	0·0165	0·397	0·0065	0·0025	0·0040	390	
5	0·019	0·490	0·0093	0·0031	0·0062	396	0·090
6	0·021	0·580	0·0122	0·0037	0·0085	401	
7	0·023	0·660	0·0152	0·0043	0·0109	411	
8	0·025	0·740	0·0185	0·0050	0·0135	420	
9	0·0265	0·810	0·0215	0·0056	0·0150	431	
10	0·028	0·885	0·0250	0·0062	0·0188	439	0 049
12	0·032	1·025	0·033	0·0075	0·0255	453	
14	0·0355	1·155	0·041	0·0087	0·032	470	
16	0·039	1·26	0·049	0·0099	0·039	492	
18	0·0425	1·36	0·058	0·0110	0·047	513	
20	0·045	1·46	0·066	0 0125	0·0535	530	2·57
22	0·047	1 56	0·073	0·0135	0·0595	547	
25	0·052	1·71	0·089	0·0155	0·0735	566	
30	0·059	1·93	0·114	0·0185	0·0955	602	
35	0·066	2·14	0·141	0·0215	0·120	633	
40	0·073	2·33	0·170	0·025	0·145	665	
45	0·079	2·52	0·198	0·028	0·170	690	
50	0·0845	2·74	0·231	0·031	0·200	707	22 5
60	0·094	3·10	0·292	0·037	0·255	750	
70	0·102	3·44	0·350	0·043	0·307	789	
80	0·108	3·76	0·406	0·050	0·356	824	
90	0·113	4·10	0·465	0·056	0·409	852	
100	0·117	4·40	0·515	0·062	0·453	880	100

Watts per lb. = $\mathbf{B}_{max.}$ × in-phase ampere-turns × 0·00000195.

It was particularly desired that the retentiveness should be measured with the highest degree of accuracy obtainable. It was necessary, therefore, to arrange that all throws

TABLE N.—LOHYS.

Showing the rate of variation of hysteresis watts and $\mathbf{B}_{max.}$ Average of readings at 25 and 50 periods.

$\mathbf{B}_{max.}$	Hysteresis Ampere-turns	Hysteretic Index
1	0·0005	3·0
2	0·002	2·7
3	0·004	2·95
4	0·007	3·0
5	0·011	3·05
7	0·022	2·85
10	0·043	

should be as large as possible. With the coils employed for the previous tests a throw to the full length of the scale could not be obtained with a value of $\mathbf{B}_{max.}$ less than about 7·5. The accuracy desired could not therefore be obtained

at lower values. The tests were made, therefore, on a high-tension transformer having a core of Stalloy. It was found that single throws varied as much as 0·5 per cent either side of the mean. By taking from 30 to 50 throws, however, the author reckons to have obtained an accuracy to 0·1 per cent, or better.

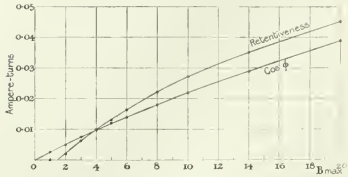

FIG. 8.—Stalloy.

The power factor was afterwards measured on the same transformer, and after allowing for eddy currents the power factor due to hysteresis alone was determined. The power factor due to hysteresis only and retentiveness are compared in Table R and Fig. 8. It will be noticed that

TABLE O.—STALLOY.

Showing the rate of variation of hysteresis watts and $\mathbf{B}_{max.}$ *Average of readings at 25 and 50 periods.*

$\mathbf{B}_{max.}$	Hysteresis Ampere-turns	Hysteretic Index
1	0·00025	3·0
2	0·0010	2·75
3	0·0022	2·9
4	0·0038	2·9
5	0·0058	2·8
7	0·0106	2·6
10	0·0186	

TABLE P.—LOHYS.

Showing the difference between the ballistic and alternating permeability taken 48 hours after demagnetization.

$\mathbf{B}_{max.}$	Permeability		Difference	Per cent
	Ballistic	Alternating		
0	286	245	41	14·3
5	306	270	36	11·8
10	332	296	36	10·8
20	375	345	30	8·0
30	410	385	25	6·1
50	470	450	20	4·3
75	525	507	18	3·4
100	572	555	17	3·0

the curves cross at $\mathbf{B}_{max.} = 4$, and whilst $\cos\phi$ appears to reach zero at $\mathbf{B}_{max.} = 0$, the retentiveness reaches its zero value at $\mathbf{B}_{max.} = 1·5$. It is certain that at $\mathbf{B}_{max.} = 1$ no retentiveness whatever could be detected. It is also certain that on alternating current no amount of adjustment or allowance for possible errors could cause $\cos\phi$ to come out lower than 0·002 at $\mathbf{B}_{max.} = 1$.

The conclusion appears to be that the hysteresis loss per cycle is not independent of the frequency at these very low inductions.

TABLE Q.—STALLOY.

Showing the difference between the ballistic and alternating permeability taken 48 hours after demagnetization.

$\mathbf{B}_{max.}$	Permeability		Difference	Per cent
	Ballistic	Alternating		
0	400	350	50	12·5
5	415	395	20	4·8
10	465	440	25	5·7
20	565	530	35	6·2
30	640	605	35	5·5
50	750	715	35	4·7
75	850	815	35	4·1
100	910	885	25	2·7

There is one discrepancy which ought in fairness to be mentioned. Some two years ago, when the author knew but little of the necessity of keeping to standard conditions, this same transformer was tested for retentiveness and it

TABLE R.—STALLOY.

Showing the comparison between ballistic retentiveness and the power factor after deducting eddy currents.

$\mathbf{B}_{max.}$	Cos ϕ	Retentiveness
1	0·0025	Nil
2	0·005	0·002
3	0·007	0·006
4	0·0095	0·010
5	0·012	0·013
6	0·014	0·016
8	0·018	0·022
10	0·022	0·027
14	0·029	0·035
20	0·039	0·045
100	0·105	0·125

was then found that the retentiveness curve reached zero at $\mathbf{B}_{max.} = 3·5$. What the special conditions were that brought this result about, the author has tried and failed to ascertain.

It should be mentioned that all the tests referred to in this paper were carried out at a practically constant room temperature, namely between 64° and 66° Fahr.

CONCLUSIONS.

Subjecting the iron to demagnetizing treatment has a sort of loosening effect upon the molecular magnets, so that directly afterwards reversing the magnetizing force leads to an abnormal change of flux and an abnormally high permeability.

A series of sharp blows given to the iron whilst not subjected to a magnetizing force has a similar effect to the above.

In both cases the effect wears off with time, 48 hours being about the time required to reach normal conditions.

At flux densities between $\mathbf{B} = 1$ and $\mathbf{B} = 100$ the process of magnetization is so slow that no ordinary ballistic galvanometer can include the whole change of flux on reversal of the magnetizing force.

When the reversal of magnetizing force is divided into two parts, the change of flux takes place even still more slowly than on a simple reversal, so that attempts to measure the hysteresis loss ballistically are likely to be very misleading.

Permeability on alternating current is sensibly the same at 50 as at 25 periods. Ballistic permeability is higher and true continuous-current permeability the highest of all.

The hysteretic index is in the neighbourhood of 3 on alternating current between $\mathbf{B}_{max.} = 1$ and $\mathbf{B}_{max.} = 10$. Above $\mathbf{B}_{max.} = 10$ the index continually declines, but it is still above 2 at $\mathbf{B}_{max.} = 100$.

On alternating current hysteresis loss is present right down to $\mathbf{B}_{max.} = 0$, notwithstanding the fact that no retentiveness could be detected below $\mathbf{B}_{max.} = 1$ on ballistic tests.

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DYNAMOS FOR MOTOR ROAD-VEHICLE LIGHTING.

(SECOND PAPER.)*

By J. D. MORGAN, Associate.

(*Paper received 20th October, 1913.*)

In a former paper † the author described a number of representative generators for use in the electric lighting of motor road-vehicles. The present paper is intended to be supplementary to the former one, and gives an account of the more importantor more representative machines of a number which the author has recently had occasion to test.

The question of efficiency has not yet become of serious importance in car-lighting dynamos, as the power required by them is comparatively small, and the necessity for good regulation over a large range of speed variation is greater than the demand for economical generation. There is, however, at present a movement in the direction of making the dynamo convertible, so that it can also be used as a motor for engine-starting purposes. In this connection it is necessary to give attention to efficiency if the machine is

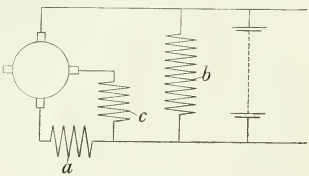

FIG. 1.

required to run without modification as a motor. Efficiency tests have therefore been made on the machines described. Such tests are based upon measurements of the net tension of the driving belt.

MACHINES WITH COMPENSATING WINDINGS.

It is well known that if in conjunction with a pair of ordinary brushes placed centrally between a pair of poles there is employed an extra brush placed mid-way between the two ordinary brushes and connected to one of these through a field winding, the current through the said winding reverses its direction after a certain speed has been exceeded. This fact is utilized in an ingenious manner by Messrs. Joseph Lucas, Ltd.

Fig. 1 illustrates the arrangement of the windings in a machine recently produced by them. Three distinct windings are adopted, *a* being a series winding connected to the negative brush, *b* a shunt winding connected to the positive brush and the end of *a* remote from the negative brush, and *c* a shunt winding connected between the intermediate brush and the junction of the windings *a* and *b*. The machine is adapted for operation with an 8-volt battery of about 75 ampere-hours' capacity. At low speeds all the windings contribute to the excitation of the machine, but as the speed increases the current flowing through *c* diminishes, and the excitation is correspondingly diminished. Above a certain speed the current through *c* reverses in direction and increases with further increase of speed. Simultaneously the current in *a* diminishes until it finally reaches zero value, the return to the machine being then entirely through the winding *c*. The excitation therefore progressively diminishes with increase of speed, and the action of the windings *a* and *c* enables an extraordinary amount of field variation to be obtained. With

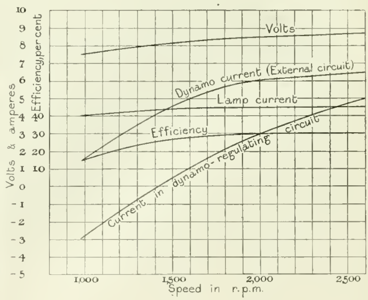

FIG. 2.

this arrangement the regulation is very good, as is shown by Fig. 2. The voltage and current increase to a maximum and then remain practically constant, notwithstanding a large increase in the speed of rotation. In the figure only the earlier portion of the test is recorded, as it is the behaviour at the lower speeds which enables an opinion to be formed of the merits of these machines, provided, of course, that at the higher speeds there is no serious variation of voltage or current; for in addition to the necessity for constancy of the maximum voltage it is important that the maximum should be reached quickly, and when the voltage rise is slow the range of speed over which the machine is useful is limited.

It will be observed that the maximum output of the machine is only about 2 amperes higher than that required by the lamps. The necessity for this was indicated by the author in the earlier paper, and it is interesting to note that manufacturers are generally

* *Journal I.E.E.*, vol. 48, p. 749, 1912.
† *Loc. cit.*

realizing the fact that a current output largely in excess of the requirements is detrimental both to the battery and the regulation. When it is impossible to avoid a relatively excessive output at high speeds means are sometimes adopted for cutting out the dynamo from the system after the current has exceeded a predetermined value.

The efficiency of the Lucas machine, as in all electrically regulated machines, is low, being only 30 per cent at

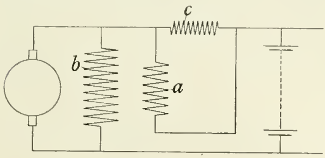

FIG. 3.

the highest. But this figure remains remarkably constant after it has been attained, a result due no doubt to the fact that the winding *a* goes out of action at the higher speeds.

In the same class as the above is the machine of Messrs. Rushmore, Ltd. This is illustrated in Fig. 3. A demagnetizing winding *a* is employed in conjunction with

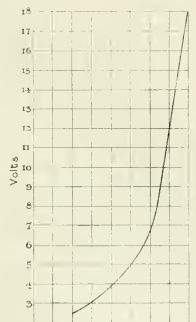

FIG. 4.

an ordinary shunt winding *b*. The winding *a* is arranged in shunt with an iron-wire resistance *c*. Regulation of the demagnetizing current through *a* is obtained by taking advantage of the known peculiarity in the variation of the temperature coefficient of resistance of iron. When a small current passes through *c* the potential drop in the coil is small, and in consequence the winding *a* has little effect upon the operation of the machine. But as the current through *c* increases, the potential difference across the ends of the coil increases largely, and in consequence a rapidly increasing current is diverted through the winding *a*. This result, though depending upon a perfectly well-known property of iron, finds an interesting application in the Rushmore machine, and a curve is therefore shown in Fig. 4 to illustrate the variation of potential and current in an iron-wire coil. From this it is evident that small variations in the higher values of the current passed through the coil would cause relatively large variations in the current through a winding connected to the ends of the coil.

The machine tested was adapted to operate with a 6-volt

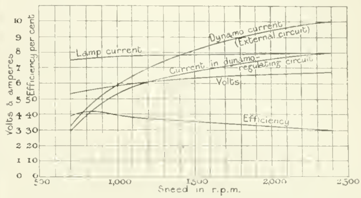

FIG. 5.

battery, and in the tests a battery of about 75 ampere-hours' capacity was used. A typical result of a large number of tests is shown in Fig. 5. It will be seen that the regulation is good, and the efficiency, though low, is of the same order as is usually found in this class of machine. Compared with the Lucas machine the efficiency curve possesses a different characteristic in that it gradually falls from the maximum with an increase of speed.

MACHINES UTILIZING ARMATURE REACTION.

Of this class the machine made by Messrs. Brolt, Ltd., is a good example. In its simplest form (which is illustrated by the diagram in Fig. 6) it consists of an ordinary shunt-wound dynamo fitted either with exceptionally broad brushes or with an equivalent pair (*a*), each of which consists of two electrically connected parts arranged so as to subtend a large arc on the commutator and to short-circuit a number of coils on each side of the armature. According to the makers, the object aimed at is to short-circuit those armature conductors which are intersecting the cross-field produced by the conductors under the main pole-pieces, and by the currents thus obtained to create a

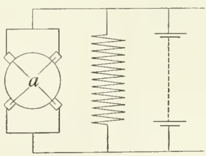

FIG. 6.

regulating flux which directly opposes the main flux. Auxiliary poles (wound or unwound) may be arranged adjacent to the short-circuited conductors to intensify the cross flux. In the machine tested there were no auxiliary poles and the brushes were of the divided type as illustrated.

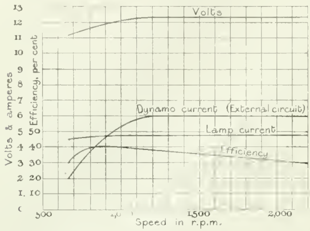

FIG. 7.

The machine was designed to work at 12 volts and was tested in conjunction with a battery of 75 ampere-hours' capacity. Fig. 7 gives curves which are representative of

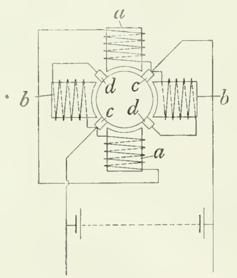

FIG. 8.

the normal working of the machine. The high quality of the results is self-evident, the maximum voltage being quickly reached, and both the voltage and the current being kept constant over a wide range of speed variation. The efficiency curve has a somewhat similar characteristic to that of the Rushmore machine, and is similar to the curves usually obtained in electrically regulated machines.

Another machine which depends upon armature reaction for its self-regulating property is that made by Messrs. C. A. Vandervell & Co. One of the most recent forms of their machine is illustrated in Fig. 8. It consists of a pair of main pole-pieces *a* and a pair of auxiliary pole-pieces *b*. The former are provided with an ordinary shunt winding, and each of the latter is fitted with a winding which is connected between one of the main brushes *c* and an auxiliary brush *d*. The action of the machine in detail is somewhat complicated.* But in the main the action appears to be as follows:—At low speeds the conductors between the brushes *c* and *d* cutting the residual magnetism of the pole-pieces *b* produce a current in the windings on *b*, the flux due to which opposes the said residual magnetism. When the speed increases beyond that at

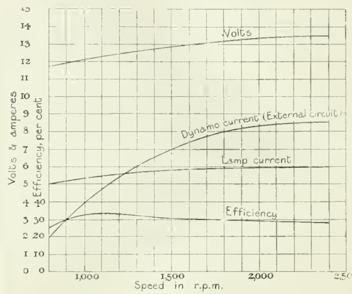

FIG. 9.

which the residual magnetism of the poles *b* is neutralized, the direction of the current through the conductors between *c* and *d* and the windings on *b* reverses, whereupon a field is produced which acts in opposition to the field of the pole-pieces *a*. This opposition increases with the speed and produces the required regulation at the higher speeds. A typical result of tests on this machine is shown in Fig. 9, from which it will be seen that the regulation is good.

At the present time the electrically regulated machines appear to be more in favour than those which are regulated by a slipping clutch. The mechanical simplification obtained in the electrically regulated machines is not, however, an unmixed blessing, as special precautions have to be taken to avoid injurious effects from over-heating.

* A full account is given in the British Patent Specification No. 17838 of 1912.

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THE EMPLOYMENT OF POWER IN H.M. POST OFFICE.

By H. C. Gunton, Member.

(*Paper first received 6th October, and in final form 24th November*, 1913; *read before* The Institution 18*th December, and before the* Manchester Local Section 16*th December*, 1913.)

Synopsis.

I. Introductory.

One of the author's objects in presenting this paper is to dispel an idea, which he believes generally exists outside the Post Office, that engineering work in the Post Office is practically confined to telegraphy and telephony. As a matter of fact the various applications of power cover a considerable proportion of the whole field of power engineering, including the generation and conversion of electric power, pneumatics, hydraulics, heating, ventilation, transportation, and lighting, as well as those applications directly connected with telegraph and telephone circuits.

It is hoped that the following particulars of the problems which present themselves and the manner of their solution will be of interest to members, and that their publication may also serve as an inducement to engineering contractors to interest themselves in designing plant to meet the required conditions. It will only be possible within the limits of a single paper to indicate briefly what is being done and attempted, and the author must also request the indulgence of members as regards the absence of much information which, for official reasons, he is unable to give.

II. Generation and Conversion of Power.

Until recently the energy for power and lighting in London and seven of the larger provincial towns has been supplied from small power houses situated in the basements of the Post Office buildings, and some of these stations have been in existence for about 20 years. In the Metropolitan area two of these old power houses have recently been replaced by the new electric power system which has been laid down to meet the growing demand for power, and to generate under more economical conditions.

The new system at present includes a main generating station and three sub-stations, the generating station being situated on the south side of the river, near Blackfriars Bridge, and the three sub-stations being in basements at King Edward Building, G.P.O. West, and Carter-lane.

Fig. 1 is a key diagram of the power supply. Electric power is generated as three-phase alternating current with a frequency of 50 periods per second, and at a pressure of 6,600 volts, and transmitted at this pressure to the three sub-stations.

At G.P.O. South (Carter-lane) the three-phase supply is transformed down to 110 volts for the supply of the lighting circuits.

At King Edward Building the three-phase supply is transformed down to 440 volts for power and to 110 volts for lighting.

At G.P.O. West sub-station the three-phase supply is converted by motor converters to continuous current at 220 volts, the power circuits being supplied from the outers and the lighting circuits from either side of a 3-wire system worked in conjunction with a storage battery.

By means of suitable relays at the sub-station end of the extra-high-tension feeders and in the continuous-current busbars it has been arranged that in the event of temporary interruption to the e.h.t. supply from the power house the battery will for a considerable time not only maintain the supply to the continuous-current circuits but will also by running the motor converters reversed as e.h.t.

generators automatically maintain the pressure on the e.h.t. busbars at the other two sub-stations, and so enable the transformers to maintain the alternating-current supply.

The normal full load capacity of the main generating plant, including spares at the power house, is 2,500 kw., and the corresponding capacity at the sub-stations is 1,200 kw. at G.P.O. West, 900 kw. at King Edward Building, and 300 kw. at G.P.O. South. A full description of the plant was given in a paper read by the author before the Institution of Post Office Electrical Engineers in November, 1910, and was also published in the technical journals; it is not therefore proposed to repeat it in this paper.

Table A (see p. 112), giving an extract from the weekly analyses of operation, and Fig. 2, which illustrates a representative load curve, will probably be of interest. Although the present total output is so small the extremely favourable character of the load curve has enabled us to supply energy for all purposes at a cost of approximately 1½d. per unit delivered.

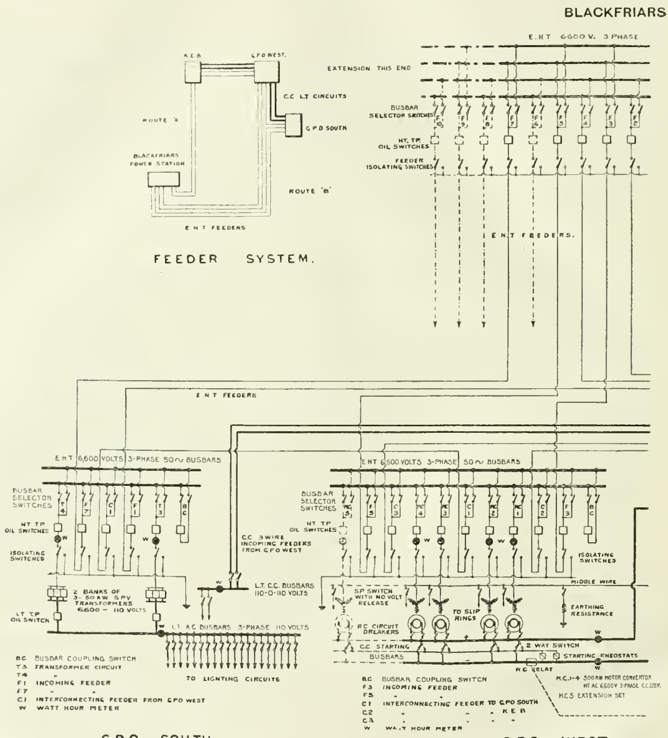


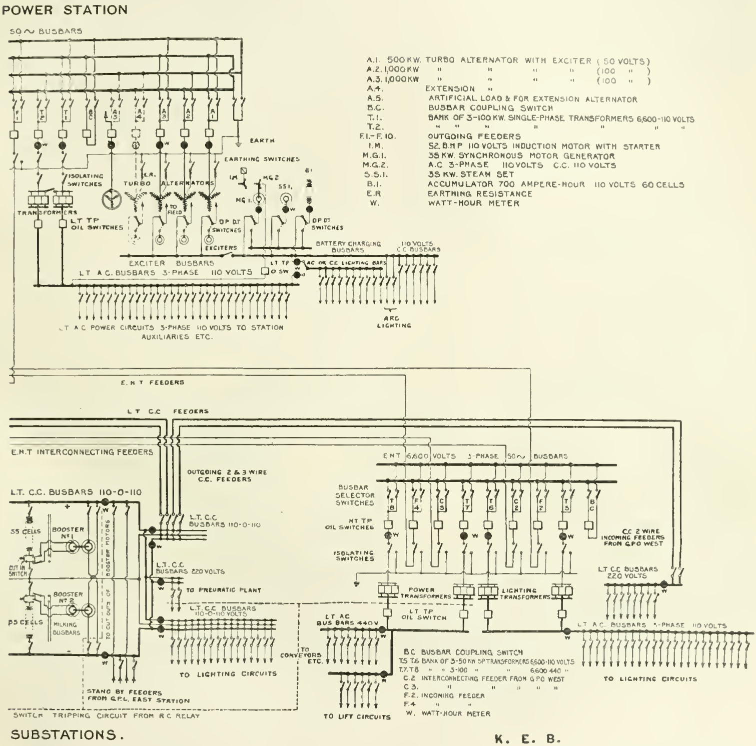
FIG. 1.—Key Diagram of

As regards the provincial stations, arrangements have recently been made in several instances to change over to the local municipal supplies, this course being rendered advisable owing to the approaching obsolescence and wearing out of the plant, to the inability to deal with the

growing demands in the space available, and to the favourable arrangements which it has latterly been possible to make with certain local authorities.

Owing to the fact that the exhaust steam supplemented by a certain amount of live steam has been used for heat-

In some cases the favourable load curve has enabled a sufficiently low price to be obtained for a direct supply at the standard low pressures for power and lighting without special arrangements, this result being facilitated by the recent improvements in metal filament lamps and their



G.P.O. Electric Power Supply.

ing purposes it has not been so easy to justify the shutting down of these non-condensing stations on purely financial grounds as might be imagined. In each case, the existing cost of supplying all services has had to be carefully compared with the cost of the purchased electrical units, plus the cost of additional heating and steam cooking plant, taking into consideration of course the capital charges involved in each case.

employment in groups of high-candle-power units for general lighting. In other cases the required price per unit has been obtained by installing a battery to enable the value of the local factor to be increased, the advantage also being obtained of a stand-by for emergency purposes.

At Birmingham an e.h.t. bulk supply is taken from the Corporation in the form of three-phase current at 25 periodicity and 5,000 volts pressure, and is transformed

and converted by rotary converters to continuous current of 220 volts, the power circuits being supplied from the outers and the lighting circuits from the inners of a 3-wire system worked in conjunction with a battery. The Birmingham sub-station contains two 150-kw. rotary converters and two 10-kw. boosters, the battery which has a capacity of 750 ampere-hours at the 3-hour rate being placed in a room overhead. The sub-station also accommodates two pneumatic pumping sets, each driven by a 34-kw. motor.

The lifts in the building which have been worked by hydraulic power will ultimately be replaced by electric

TABLE A.—G.P.O. POWER SYSTEM.

Extract from Analysis for week ending 25th April, 1913.

Units generated, etc.	Units.
A Total e.h.t. output to sub-stations for lighting and power	115,160
B Excitation	1,545
C Works—Lighting and power	6,450
C′ " Testing and special	—
D Total units generated = A + B + C + C′ ...	123,155
E Units generated by main generators, not including C′ = A + C	121,610
F Momentary maximum output (e.h.t.) to sub-stations	1,156 kw.

$$\frac{\text{Units used for excitation}}{\text{Units generated by main generator}} = \frac{B}{E} = \frac{1545}{121610} = 1{\cdot}27\ \%$$

$$\frac{\text{Total output (e.h.t.)}}{\text{Total generated including excitation, lighting and power, but not C}'}$$
$$= \frac{A}{A+B+C} = \frac{115160}{123155} = 93{\cdot}4\,\%$$

$$\text{Running load factor} = \frac{E}{\text{Running-plant-capacity} \times \text{hours}} = 70{\cdot}2\%$$

$$\text{Weekly load factor} = \frac{A}{F \times 168} = 59{\cdot}2\ \%$$

Average power factor, 98 % lag.

Coal used = 195·3 tons. Lb. per unit $= \frac{(\text{lb.})}{(D)} = 3{\cdot}55$ lb.

Water evaporated = 2,617,460 lb. Lb. per unit $= \frac{(\text{lb.})}{(D)} 21{\cdot}3$ lb.

Evaporation per lb. of coal, 6·0 lb.

Overall efficiency of transmissions (a.c. and c.c.) transformation and conversion (including battery losses), 87·4 %.

lifts, the service being maintained in the meantime by temporary electrically-driven hydraulic pumps.

III. PNEUMATICS.

Pneumatic tubes have been used in London since 1871, and in Dublin, Glasgow, Liverpool, Manchester, Birmingham, Newcastle and other places prior to 1896, while since the latter date their use has been extended in some form or another to practically every telegraph office of appreciable size in the kingdom, the total capacity of the power-driven pumping plant installed for this purpose being about 2,200 b.h.p. In the earlier installations the pumps were driven by steam engines or gas engines, but it is now the practice to employ electrically-driven pumps. The original four 120-h.p. engine sets at G.P.O. West have recently been replaced by four electrically-driven 240-b.h.p. sets each having a free air capacity of 3,600 cubic ft. of air per minute, which are operated from the new electric power system.

For smaller installations, where space is not quite so important as at the G.P.O., low-speed sets belt-driven from electric motors are usually employed, and, generally speaking, lend themselves to the most efficient and economical working. Water-cooled cylinders are employed in all cases, and air containers, both pressure and vacuum, are provided as required. Several systems of automatic regulation are in use, electrically operated valves of our own design used in conjunction with pressure gauges fitted with contacts and relays having given the most satisfactory results. A system of "pumping through"* by which the air drawn from the vacuum mains is compressed and used for the pressure service, has been adopted with advantage in some cases and is in use at the General Post Office; it results in a saving in the space required and in a slightly

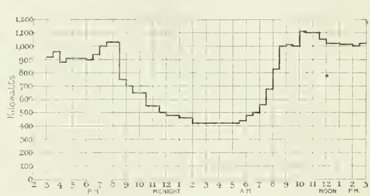


FIG. 2.—Daily Load Curve (25th April, 1913) of G.P.O. Power Station at Blackfriars.

Load factor = 73·4 per cent.
Running plant load factor = 80·1 per cent.
Average power factor = 0·98 lagging.

higher overall efficiency although it has certain disadvantages, especially as regards the increased air-delivery temperature and the danger of drawing in gas through leaky street tubes, and both these matters have to be specially guarded against. For the house tube systems, described below, rotary blowers maintaining a constant flow of air through the tubes are extensively used and are very economical in use.

The pneumatic power is employed for connecting head telegraph offices with branch offices by means of "street" tubes of 1½ in., 2¼ in., or 3 in. internal diameter, and for distribution purposes in the buildings themselves by means of "house" tubes of 1½ in. or 2¼ in. internal diameter, the carriers in which the messages are placed taking one of the forms illustrated by the samples.

For "up" tube working a vacuum of about 7 lb. below atmosphere and for "down" tube working a pressure of about 10 lb. above atmosphere have been employed. In actual practice about 5–5½ horse-power is required to work a 2¼-in. tube one mile long continuously at 10 lb. pressure, the time occupied in the transit of the carrier being 2¼–2½ minutes. For the same speed with vacuum working the horse-power required would be less in the proportion of 1·83 to 1.

* *Post Office Electrical Engineers' Journal*, vol. 2, p. 32, 1909–10.

Full particulars of the general methods of working, including the terminal arrangements and signalling systems which have been in use for many years, will be found in a paper read before the Institution of Post Office Electrical Engineers by Mr. H. R. Kempe on 11th October, 1909, on "Pneumatics," and also in an article* by Mr. D. H. Kennedy on "Pneumatic Tube Services."

It has been necessary for the author more particularly to confine himself in this paper to the latest methods of working which have been evolved.

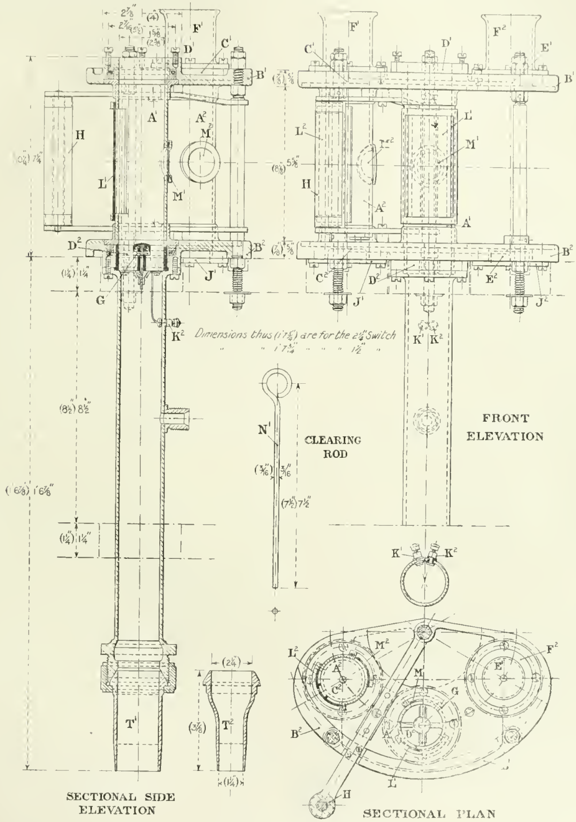


FIG. 3.—Double-slide Switch Pneumatic.

In order to accelerate the insertion and extraction of the carriers, and to ensure that the flow of air in the tube may be affected to the minimum extent by these operations, a new form of terminal switch illustrated by Fig. 3 has been substituted for the old sluice and slide valves with very

* *Post Office Electrical Engineers' Journal*, vol. 2, p. 26, 1909–10.

satisfactory results. The sliding portion of the switch merely consists of two sections of tube, either one of which by operation of the switch is brought into line with and forms part of the main tube while the other section is free for the insertion or discharge of a carrier.

On street tubes block-signalling apparatus is employed, and on long tubes an automatic regulator is also employed which gives a clearing signal after a fixed interval of time and provided clearing signals are being received from the receiving station; by this means the time interval between carriers in a tube is easily controlled, and although a tube is carrying a continuous stream of carriers the effect of a blockage is minimized and is limited to a definite number of carriers. In many cases three offices which may be some distance apart are served by one tube; in this case an intermediate switch is fitted at the intermediate office, and in some cases coloured carriers are used to distinguish between traffic for the intermediate and the terminal offices.

In the case of two long tubes to the West End of London, on which the traffic is at times very heavy, special arrangements have been made for accelerating the working during the busy hours. The "up" and "down" tubes are looped together at the distant end through a 3-way rotary switch, and a pressure of 20 lb. per sq. in. is applied at one end of the loop and a vacuum of 8 lb. per sq. in. at the other.

The particulars of these tubes and the transit times are as follows:—

Length in yards	Diameter	Transit Time (Average for New Carriers, in seconds)	
		Up	Down
4,180	3 in.	375	464
3,000	3 ,,	245	336
3,609	$2\frac{1}{4}$,,	364	480
4,051	$2\frac{1}{4}$,,	452	535

Such an arrangement is of course only justified by the extremely heavy traffic and the high capital cost of the tubes; during the slack hours the normal pressure of 10 lb. per sq. in. is used.

For short street tubes and house tubes through which the traffic is continuous over considerable periods a system has been used in which the tubes are connected in series and a current of air is maintained through them by means of an electrically-driven rotary blower. The carriers are inserted in an orifice closed by a flap and are automatically discharged at the terminal through a flap; no signalling apparatus is required, the carriers moving in a stream at close intervals. A modification of this system to adapt it for intermittent working includes a remote-control starting switch to enable the motor-pump in the power room to be started from the operating room. As an indication of the economical nature of this system the power consumed in maintaining the passage of carriers at intervals of 5 to 10 seconds in a $1\frac{1}{2}$-in. tube system of a total length of 650 ft. is only $\frac{1}{3}$ kw.

Pneumatic power has recently been employed in a trunk telephone exchange for distributing, between certain points in the exchange, the tickets on which are entered particulars of the trunk connections required. Instead, however, of using tubes of circular section and carriers such as have been described above, the tubes are of rectangular section $2\frac{3}{8}$ in. × $\frac{3}{8}$ in. and the tickets are propelled through them by means of a folded end at right angles to the remainder of the ticket, which practically serves as a sail when pressure is applied and which also enables the ticket to be drawn through the tube when a vacuum is applied. The tickets are conveyed from various operators to a distributing centre by vacuum, and are thence dispatched by pressure to other operators; at the distributing centre the tickets are discharged without destroying the vacuum by means of two electrically-driven rollers which except during the passage of the ticket are kept in contact by springs on their axles—the tickets are also inserted in the vacuum tube by means of an arrangement which reduces the opening to the atmosphere to a minimum. The dispatch from the distributing centre is effected by placing the ticket in a receptacle and afterwards applying the pressure by means of a valve actuated by a plunger which also lights a signal lamp. The ticket on being discharged strikes a lever which breaks a contact which has the effect of de-energizing the electromagnet in connection with the pressure valve, and so cuts off the pressure from that particular tube and extinguishes the lamp.

A full and illustrated description of the system, which has been installed by the Western Electric Company, will be found in an article by Mr. H. P. Brown in the *Post Office Electrical Engineers' Journal.**

IV. Lifts.

While it has been the practice for any hydraulic lifts in post office buildings to be installed by H.M. Office of Works, the Post Office Engineering Department is responsible up to the present time for the installation and maintenance of no less than 207 electric lifts (representing a total motor capacity of 1,669 b.h.p.) which are operated from every kind of electrical supply and embody almost every system of control. While in most cases a continuous-current supply has been available we have in the new King Edward Building an installation of 12 lifts of from 5 cwt. to 5 tons capacity operated by three-phase current at 440 volts and 50 periodicity as regards the main circuits, and by continuous current at 210 volts as regards the control circuits.

At the Sheffield Head Post Office we have three lifts operated by a two-phase 50-period 200-volt supply, the controllers (which are of the up, down, and stop push-button and car-switch type) working from the same supply.

At the Islington Postal Stores and the Northern District Post Office there are 10 lifts working on a single-phase 50-period 410-volt supply, a separate continuous-current supply at 100 volts being provided for the control circuit. Solenoids for use on alternating-current circuits have been greatly improved both as regards efficiency and silent working since the lifts at the Postal Stores were erected, and we have installed 5 lifts at the New Money Order Office, operated by means of Bandy motors from a single-

* Vol. 4, p. 209, 1911–12.

phase supply at 440 volts and 50 periodicity, the controllers being worked from a supply at the same periodicity but at 200 volts.

In certain offices we have small lifts working on single-phase alternating-current supplies of 100 periodicity. The last-named supply, however, is naturally unsuitable for lift

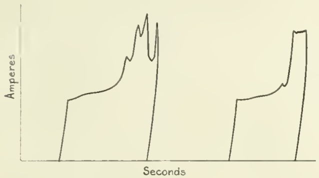


FIG. 4. FIG. 4A.

operation, and while the existing installations have been made to work fairly satisfactorily it is not desirable to install lifts on a supply of this description if it can possibly be avoided.

The general lines on which lift installations are carried out are well known to members, and it would not be

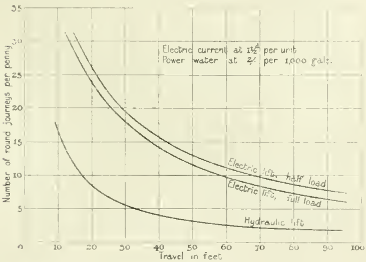


FIG. 5.—Curves showing comparison between Electric and Hydraulic Lifts of 20 cwt. Capacity and Speed of 200 ft. per minute. Electric supply 3-phase 50 ∿ 440 volts.

necessary, even if space permitted, for me to describe them in this paper, but it may be of some value to refer to results of experience which are taken into consideration when deciding whether an electric or an hydraulic lift should be installed in any particular case where both sources of power are available.

The capital cost of an electric lift is usually greater than that of an hydraulic lift except in the case of a very long travel. The average maintenance cost of an electric lift is not likely to be so great as that of an hydraulic lift, but for all practical purposes they are taken to be about the same. The cost of electric and hydraulic power varies considerably in different localities, but it is of course a simple matter to take proper account of these factors.

With regard to safety, it is considered that the possibility of an accident is reduced to a minimum with modern electric lifts, the safety appliances of which include electrical and mechanical interlocking of gates, interlocking between main and control circuits, main and control limit switches, guide grips to hold the cage in the event of a breakage of the ropes, and the provision against running away by the braking action of worm and wheel, supplemented in certain cases by a suitable emergency brake. The author believes he is right in saying that there has not been a single fatal accident with an electric lift installed by the Post Office.

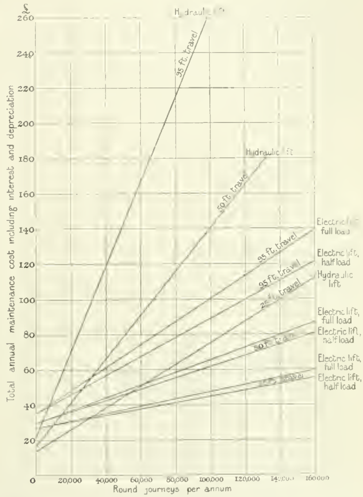


FIG. 6.—Six per cent on Capital Outlay allowed for Interest and Depreciation. Cost of electrical energy = 1½d. per Board of Trade unit. Cost of hydraulic power = 2s. per 1,000 gallons of water. Electric supply 3-phase 50 ∿ 440 volts.

The current taken by the electric lift is proportional to the load when balanced for no load, whereas the amount of water taken by the hydraulic ram is the same whatever the load. As a matter of fact it is usual to balance the cage of the electric lift for half-load, under which condition the power taken is merely that required to accelerate and overcome friction. With a view to economy at variable loads hydraulic lifts have been fitted with two rams, but this arrangement has not, so far as the author is aware, met with much success. The amount of water taken by an hydraulic lift is independent of the number of stops, whereas each time an electric lift is started there is a waste of power which is a considerable portion of the total power required for a short journey.

The greater the number of stops and the shorter the travel between floors, the less favourable is the case for the electric lift as regards the cost of operation. Careful attention to the design and adjustment of the control gear is desirable in this connection.

Fig. 4 shows a "current-time" curve obtained by means of a recording ammeter for a 15-cwt. goods lift working between floors 10 ft. apart with a controller as supplied by the maker. Fig. 4A shows the corresponding current-time curve after the controller had been adjusted so as to reduce the waste of power. The result of adjustment was that without increasing the maximum current the time taken for a complete up and down journey was reduced by 24 per cent while the energy consumption was reduced by 30 per cent.

In order to co-ordinate as far as possible the many factors referred to above a series of careful tests have been carried out on electric and hydraulic lifts of similar capacity when working under various conditions as regards length of travel. Examples of the results obtained are

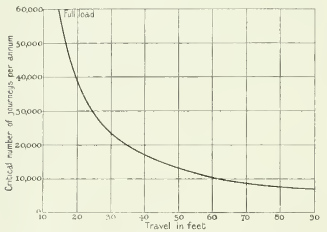


FIG. 7.—Curve showing Comparison between Electric and Hydraulic Lifts of 20 cwt. Capacity and a Speed of 200 ft. per min. Electric supply 3-phase 50 ∿ 440 volts.

shown in Fig. 5. The number of journeys per penny is plotted vertically, and the distance between the floors is plotted horizontally. From these curves it is an easy matter to arrive at the results which would be obtained for similar lifts with different lengths of travel and with different prices for current and water.

Fig. 6 shows the annual cost, including interest and depreciation, maintenance, and cost of current, plotted with reference to the number of round journeys per annum. These curves show clearly the critical number of journeys for which the annual charges in respect of electric and hydraulic lifts of a particular size are the same under different conditions of travel. To put this information in a more useful form Fig. 7 shows the critical number of journeys per annum plotted with reference to the length of travel for the same size of lift and under the same conditions as regards price of current and water.

V. CONVEYERS.

Sorting Office.—The sorting offices in the larger postal centres offer a wide but by no means an easy field for the ingenuity of the designer of mechanical appliances. Before proceeding to describe what has been done in this direction it will be well to state briefly the processes through which a letter passes in one of these offices—choosing a simple case of what is known as "outward sorting" for the purpose of explaining the objects to be kept in view.

Letters inserted in the posting boxes at the head post office, or brought in by the postmen from the local pillar boxes, say at one of the principal provincial towns, are deposited on tables and "faced" by picking them up and placing them so that the address sides all face one way with the stamp in the lower left-hand corner. The faced letters receive the locality and time impression and have their stamps obliterated. They are then taken to the primary sorting tables and sorted into 20 or 30 "roads," each of which may include several towns or districts. The letters for each road are next taken to secondary sorting or dispatch tables where they are further sub-divided and made up into bundles which are placed in bags in which they are conveyed to the railway stations. It should be stated that bags of mail matter received from the railway stations similarly pass through a process of "inward sorting" before delivery, but the above explanation of "outward sorting" will probably suffice.

It will be understood that while there are certain selective processes which can only be carried out by human agents there is scope for mechanical transportation between the processes, and the following are examples of what has been done.

Band conveyers have been employed to convey letters and packets, as they are dropped into the posting boxes, to the facing tables.

At King Edward Building (London) a ropeway has been used to convey baskets of letters posted in the Newgate-street boxes to the vicinity of the King Edward-street boxes, whence the baskets are taken up to the sorting office on the floor above by means of a band conveyer.

Slow-moving bands erected along the centre of the facing tables are used for conveying batches of faced letters to the end of the table where the stamping is done.

The stamping and obliterating in all the larger offices is now done by means of electrically-driven stamping machines which deal with 600–800 letters per minute.

The principal elements of one of these machines include :—

(i) A magazine in which the faced letters are placed by hand.
(ii) Driving rollers for feeding the letters forward into the machine.
(iii) A separating device to prevent more than one letter at a time from entering the machines.
(iv) A die and impression roller and inking pad.
(v) The mechanical stacker into which the letters finally pass, and which prevents their becoming defaced, or otherwise disarranged in a manner which would be prejudicial to expeditious sorting.

Band conveyers are employed for transporting made-up baskets and bags to the loading platform. It should be noted that a different form of delivery is required for bags and for baskets, the former being allowed to fall on the platform, or, in the case of parcel bags, into a suitable chute, while the baskets are best received and brought

to rest on gravity rollers. All the conveyers which have been installed are electrically driven.

So far the appliances which have been described are those which have been fitted in existing offices in order to facilitate operations carried out in accordance with existing ideas.

The difficulties in design involved in adapting these appliances to these operations in old offices arranged and constructed without reference to their embodiment have of course been very considerable.

Experimental Sorting Apparatus.—Experiments have recently been made which aim at the mechanical transport of correspondence practically right through an office, from the posting boxes to the dispatching tables, and thence to the loading platform.

The practicability of conveyers from posting boxes to facing tables has already been proved, and bands are also in use carrying faced letters from one end of a facing table to the other, but the experimental installation provides for the stamping machine at the end of the table being fed mechanically instead of by hand.

In framing the complete scheme it was assumed that all correspondence would be received on a platform at one end of the sorting office adjacent to the facing tables, and at this platform one man is required to watch and adjust the flow of work along the facing tables, the letters, etc., being carried by bands above these tables and deflected at will (through shoots) to the facers at their various positions along the tables. At intermediate positions (between these overhead shoots) there are openings in the table through which the newspapers and packets picked out from the general correspondence are dropped on to the return half of the band which is carried beneath the table and deposits them at the end of the table for separate treatment.

The facing table has along its edge a series of slots formed by smooth sheet-iron or wood, through which the facers drop the letters in an upright position on to a running band below the table. Each of these individual slots forms a "siding" leading to a main slot which runs from end to end of the table and into which the letters pass without "fouling." At the end of this main slot the letters are mechanically separated and fed direct into the stamping machine, and then "stacked" by the mechanical stacker which forms part of the machine.

As an alternative arrangement each small slot or "siding" is fitted with its own stamper, consisting of an impression roller and die. By this means noise is reduced, there are fewer failures, and it is possible to fit a mechanical counting device to each stamper so that the output of each facer can be ascertained. On the other hand the periodical changing of so many dies causes some additional work. The letters are automatically stacked at the end of the table.

We have so far followed the letters through the facing, stamping, and stacking processes. At this point attendance is required to transfer the stacked correspondence into boxes which, when filled, are carried away by a specially designed chain conveyer to selected points on the primary sorting table. The boxes travel along the back of the sorting table and are delivered automatically at the side of the sorters, being deflected on to moving platforms which move out to meet their respective boxes.

As the sorters empty their boxes they send them back to the machine (empty) by a similar conveyer, and the officer there refills them in turn and places them again (full) on the conveyer. As the conveyer discharges them only at the particular points from which they have been returned as empties, the sorters are kept supplied without any trouble. The primary sorting is done through a grid (*i.e.* through vertical slots) on to a wide band running below the table. For each division or "road" a slot is provided, 1 in. wide, and a sorter can have as many as 24 divisions easily within his reach.

From the primary table, the band runs to the dispatching tables, and at each "road" the slot carrying the correspondence for that particular "road" is turned outwards to the front edge of the table so as to discharge the correspondence proper to that road, and at this point it is stacked again by a mechanical stacker ready for the secondary sorting. It will thus be seen that the correspondence passes direct from one process to the next without any delay such as is inherent to hand collection.

The experimental apparatus has been installed at Liverpool Post Office, and the preliminary trials have been satisfactory and indicate a substantial saving of time over the existing methods. Improvements are at present being made in one or two points of detail and it is, of course, too early to say how far these new methods can be generally applied. The whole of this experimental apparatus is electrically driven.

It will have been gathered that the form of conveyer which has been most extensively applied in sorting offices is the moving band. While not so well adapted as other forms for routes subject to lateral variations or for selective operations, it has very great advantages for point-to-point routes, and vertical variations in route can be overcome to a considerable extent.

The fact that it is continuous and that every inch is available for the load gives it an exceedingly large capacity, while the facts that it is comparatively noiseless and safe in operation, that it is readily enclosed, and that it can be economically driven by means of an electric motor through worm, spur, belt or chain gear, render it particularly suitable for the localities in which it has to be installed.

With regard to the economical results obtained it should perhaps be stated that the installations are as a rule only authorized when it can be shown that the annual charges, including interest and depreciation, maintenance, and cost of energy are such as to show a saving as compared with the cost of labour displaced.

Telegraph Instrument Rooms.—In telegraph instrument rooms the problem has been how to displace boy labour by means of a mechanical appliance which would save time and which would meet the following conditions:—

1. The system of mechanical appliances should, as far as possible, be uniform throughout the instrument room and the control should preferably be concentrated at a central point.
2. The apparatus must be automatically selective as regards distribution to the operators, *i.e.* it must be possible to dispatch a telegram form to any desired point on any table. The forms must also be conveyed from any point on any table to the check table, but this is not a selective operation.

3. The dispatch of the telegram forms by the various operators should not involve any further break in the continuity of their work than is at present involved by the placing of the forms on the message baskets from which the boy messengers collect.
4. The apparatus must be silent in its operation, and moving parts must be arranged so as to obtrude to the smallest possible extent on the vision of the operators.
5. The gangways and the lighting of the instrument room should be interfered with to the smallest possible extent.

An experimental installation has been fitted at Birmingham. "Pick-up" carriers bring the incoming telegrams from the various operators' stations and drop them on to band conveyers, which deliver them at the "check" table, whence they have to be distributed selectively to the operators who deal with the outgoing circuits. This selective distribution is effected by placing the telegrams on tablets arranged vertically in groups of 5 or 6 corresponding to the various stations on each table. The endless cord running between the "central check" and each table draws the selective carriers, the jaws of which are made to open and close by means of ramps, and so pick up the telegrams only from their proper tablets and similarly deliver them only at their proper stations. The carriers also pick up at the table stations and deliver on to the bands at the check table referred to above. The carrier installation has been supplied by Messrs. Lamson, while the band conveyers have been installed by the Post Office. The cord and band conveyers are driven by electric motors placed underneath a platform at the "central check."

VI. Heating and Ventilation.

With certain exceptions the heating plant in the larger post office buildings is installed by H.M. Office of Works, but its maintenance is in the hands of the Post Office engineers, who now have some 600 installations to attend to, and who usually carry out any re-arrangements which become necessary from time to time. All cases of mechanical ventilation are dealt with by the Post Office Engineering Department.

Owing to the fact that in large sorting office buildings there is on one floor a large force of men whose bodies give off an appreciable amount of heat, and who are actively employed during certain hours of the day, while on other floors the clerical and other sedentary duties are performed by a comparatively scattered force, it will be evident that the heating and ventilation systems have to be very carefully designed. Almost every kind of heating system has been applied, including high-pressure hot water, low-pressure hot water with either boilers or calorifiers heated by live or exhaust steam when available, and an exhaust steam system with extractor pumps. The usual system adopted is the low-pressure hot-water system with or without forced circulation, according to the local circumstances, and with separately controlled radiators.

A description of the system of heating and ventilation installed at King Edward Building may perhaps be of interest. The heating of this building is carried out by some 400 radiators on the low-pressure hot-water system. Where radiators are fitted against the outer walls ventilators are installed so that the fresh air is warmed on its way to the building. The water is heated in 12 calorifiers placed in six pairs in different parts of the basement. The calorifiers are provided with steam at 60-lb. pressure from boilers of the Lancashire type. The basement and subground floor with total cubical contents of 1,300,000 and 1,400,000 cub. ft. respectively are provided with 16 ducts 8 sq. ft. in area, of which 12 terminate in fan houses on the roof of the sorting office block and the remainder on the roof of the public office block. The ducts are connected in pairs in the fan houses, and each pair is fitted with a fan having a capacity of 20,000 cubic ft. of free air per minute on the sorting office block and 9,000 cubic ft. of free air on the public office block. Fresh air enters the basement by means of staircases and lift wells and the sub-ground floor by the same means together with windows.

The ground-floor sorting office has a total cubical content of 1,270,000 cubic ft., and is provided with six ducts each of 4 sq. ft. area, of which four are connected to a fan on the roof of the sorting office block, with a capacity of 80,000 cubic ft. of free air per minute, and the remainder in pairs to fans, each having a capacity of 15,000 cubic ft. of free air per minute. Fresh air is freely admitted through windows and ventilating radiators.

These fans, which are of course electrically driven, will change the air of the various floors at a rate varying from a minimum as produced by unaided ventilation to a maximum forced circulation of 2·5 to 3 changes of air per hour.

It is found during mild weather in the winter when the outside temperature varies from 48° F. to 55° F., that although an equable temperature of 60° F. is maintained in the building during slack periods, it is necessary to shut off the heating system at the busy hours (early morning and early evening) owing to the fact, referred to above, that the temperature is greatly increased owing to the increase in the number of men employed, and also to a slight extent from the electric lighting system (clusters of metal-filament lamps); otherwise temperatures exceeding 60° F. are obtained.

Considerable difficulty has been experienced with the ventilation of telephone exchange switch-rooms, owing to the high switchboards interfering with the natural circulation of the air. Most satisfactory results have, however, been obtained by installing suspended fans of the revolving type between the switchboards to circulate the air, in addition to fans in the windows for the extraction of air.

In one particular case where natural ventilation is difficult, an ozone plant has been installed with successful results.

VII. Bag Cleaning.

Several types of machines for cleaning mail bags have been tried, the most satisfactory results being obtained with the type installed at the King Edward Building. This plant consists essentially of two octagonal lattice work drums, about 10 ft. in diameter, revolving inside wooden casings connected to a filter by an air duct, which in turn is connected to a powerful blower that draws air through the drum and filter. The drum is opened at one side and the bags to be cleaned are inserted and the trap-

door closed, as is also the door in the outer casing. The drum, which is driven by an electric motor, is then set in rotation by means of belting through fast and loose pulleys, and revolves at a speed of 30 revs. per min. The cleaning is accomplished partly by mutual rubbing of the bags and partly by their dropping from the top to the bottom of the drum. The heavier particles, such as wax and string, fall into a hopper at the bottom of the casing and are collected in a sack. The lighter particles are drawn through the air trunk to the filter, which consists of an iron case divided into three partitions, each connected to the blower. Each partition contains eight filter hoses, the bottom of each being connected to the air trunk from the drum. Their upper ends are closed by an iron cover suspended from rocking levers. The fabric of these hoses is of such a nature that the dust is retained on the inside of the hoses. The rocking levers are connected with a mechanism which at fixed intervals automatically draws the hoses tight and then allows them to fall back again to the slack position, thus thoroughly shaking the dust from the fabric.

The hoses in each compartment are alternately cleared of the adhering dust at fixed intervals, the suction of the fan being cut off from the compartment in which the hoses are being shaken by means of a baffle which simultaneously opens a passage giving free access to atmospheric air. The latter enters the partition with more or less power according to the vacuum created by the fan and penetrates the hose from the outside, thus materially assisting the mechanical shaking in the removal of the dust. The dust falls to the bottom of the filter into a screw conveyer and is fed into a hopper from which it is collected in a sack. This cleaning operation occurs about every five minutes in each partition separately, and as there are three compartments the exhausting and filtering process is never interrupted. The charge of bags is rendered completely clean in about 20 minutes, the total capacity of the plant being about 400 bags per hour.

VIII. Telephone Exchange Power Plant.

A large amount of plant is in use in connection with central-battery telephone exchanges, motor-generators and accumulators being almost exclusively used for this purpose although in a few cases it has been necessary to install oil or gas engines. With the exception of the generators this plant follows the usually accepted practice and does not call for any special description; the generators are, however, specially designed to give silent working when supplying the telephone-exchange circuits direct without any battery in circuit. Such conditions are very difficult to meet, and until recently satisfactory machines could only be obtained from America. Their manufacture has, however, been developed by two or three English firms, and satisfactory English-made machines can now be obtained. Their chief features are ring-wound armatures with a large number of commutator segments, uniform distribution of the field, good balancing both mechanically and electrically, good commutator surface and a special type of high-conductivity brushes; large choke coils of special design are also used in conjunction with the machines. The machines are built in sizes from 1 to 40 kilowatts. As showing the extent of this work the author might mention that upwards of 40 exchanges had to be equipped very rapidly in connection with the taking over of the National Telephone Company's system.

IX. Electric Lighting.

The extent to which electric power is used for the lighting of post office premises will be gathered from the following table showing the equivalent number of 8-c.p. lamps connected for the past five years:—

At end of—	Total No. of Offices Lighted Electrically	Total No. of Incandescent Lamps in 8-c.p. Equivalents			Increase on Previous Year	
		Metal Filament	Carbon	Metal Filament and Carbon	Offices	Lamps (Metal Filament and Carbon)
1908–9	427	31,164	120,148	151,312	—	—
1909–10	469	49,836	115,106	164,942	42	13,630
1910–11	530	197,320	58,740	256,060	61	91,118
1911–12	592	284,559	37,616	322,175	62	66,115
1912–13 (including ex-N.T.Co.'s Offices)	850	380,439	20,345	400,784	258	78,609

The consumption of energy has not increased in the same proportion owing to the introduction of metal-filament lamps; in fact, an annual saving of not less than £8,000 has been effected by the substitution of metal-filament for carbon-filament lamps after allowing for the increased costs of renewals; approximately 4,300 kw. is now absorbed for lighting purposes.

Up to the last few years the lighting in sorting offices and in telegraph and telephone instrument rooms was carried out by means of arc lamps, or by carbon-filament lamps placed singly in close proximity to the points at which the work is done. A system of general lighting by means of clusters of metal-filament lamps contained in fittings with opalescent shades has now been adopted

for the larger offices, and is found to have the following advantages :—

1. A soft well-diffused light is obtained with comparative absence of shadow and eye-strain.
2. The lamps are not subject to vibration to the same extent as when fixed to the sorting or other fittings.
3. The lighting installation is practically independent of the position of the sorting fittings and re-arrangement of the latter does not therefore necessitate alteration to the former.

The lighting installation can also be completed without waiting for the sorting fittings to be supplied, which has proved an important point in cases of urgency. To obtain the full advantages of this system of lighting it is very desirable that walls and ceilings should have dull white or cream surfaces, and any large windows should be provided with light blinds.

As the result of careful experiment it has been found that the amount of illumination in foot-candles which it is necessary to provide for various purposes, is as shown in the following table :—

Screwed conduit is now used in preference to wood casing for internal wiring.

X. Post Office (London) Railway.

As members are doubtless aware, powers have recently been obtained to construct an electric railway for purely postal purposes between the Paddington District Post Office in London Street and the Eastern District Post Office at Whitechapel, with intermediate stations at the Western District Parcel Office, at the Western District Post Office, at the Western Central District Post Office, at Mount Pleasant Sorting Office, at King Edward Building Post Office, and at Liverpool-street Station.

The railway contemplated under the present scheme is indicated by the full lines in Fig. 8, while the ultimate extensions contemplated are shown by the dotted lines. Between the stations the railway will consist of two tracks each 2 ft. gauge, one for east-bound and the other for west-bound traffic, and contained in a single tunnel of 9 ft. internal diameter.

A complete scheme has been worked out in detail in collaboration with Mr. Dalrymple-Hay. The latter is responsible for the tunnelling, while the Engineer-in-Chief of the Post Office is responsible for the equipment.

Part of building	Max. foot-candles	Min. foot-candles	Average foot-candles	Where measured
Sorting (letters and parcels)	3·0	2·0	2·5	3 ft. above floor
Instrument rooms (special)	2·5	2·0	2·25	Table height
Ditto (ordinary)	2·0	1·5	1·75	Table height
Loading platforms	1·5	1·0	1·25	3 ft. above floor
Offices for clerical work	2·0	1·0	1·5	Desk height
Stairs, passages, etc.	0·75	0·3	0·52	3 ft. from floor
Retiring rooms	1·0	0·5	0·75	Table height
Telephone exchanges (trunk)	2·0	1·0	1·5	Max. at Desk Min. at Switch
Ditto (ordinary)...	1·5	1·0	1·25	Ditto

The provision and measurement of illumination on the basis of the number of foot-candles at the level at which the work is carried on has greatly facilitated the investigation and adjustment of complaints of inefficient lighting, compared with the old basis of candle-power per square foot of floor area, as it is no longer so easy to suggest that the "square feet" or the "candle-power" are in the wrong place, or that the latter is insufficient.

In large sorting offices the required illumination has been obtained by clusters of 3 (or 4) 100-c.p. lamps suspended at a height of 13 ft., and spaced at intervals of 18 ft. In sorting offices where there is not sufficient head-room for the above arrangement, clusters of three 50-c.p. lamps have been used, suspended at a height of 10 ft. 6 in. and spaced at intervals of 13 ft. In small sorting offices single 100-c.p. lamps fitted with Holophane shades have been used with advantage, suspended at a height of 10 ft. 6 in. and spaced at 10 ft. 6 in. intervals.

In telegraph instrument rooms, where it is particularly necessary and rather more difficult to eliminate shadows, clusters of three 50-c.p. lamps, placed as in the sorting offices, are employed.

Three of the stations, viz. the Western Central District Office, Mount Pleasant, and King Edward Building, will form important junctions when extensions to the north and south are undertaken.

It is intended that the trains should be operated without drivers on the remote-control system.

The present is clearly not a convenient or proper time to give a detailed description of the scheme which, whilst it will form the basis of invitations to tender, will leave the way open for alternative proposals as regards the electrical equipment. A brief reference to the main outlines of the *model scheme* may, however, be of interest at this point in view of the information which has already been published.

A station will consist of an island platform arranged in two sections, between which will be placed a control cabin and the lifts and conveying appliances that have been specially designed to suit the different classes of postal matter which have to be dealt with between the station platforms and the postal buildings above. This is the general design of station which has been adopted in all cases, the arrangement of the tracks and of the conveying appliances being adjusted to suit the requirements at the different points.

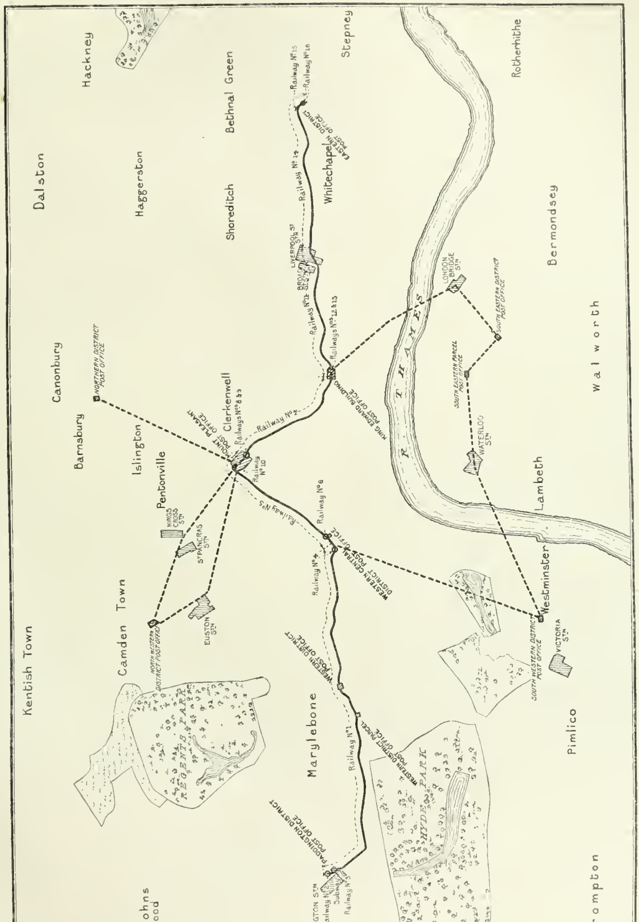


FIG. 8.—Post Office (London) Railway.

It is proposed to operate the wagons or trains by three types of current, which it will be convenient to refer to as high speed (H.S.), intermediate speed (I.S.), and low speed (L.S.). Between the stations H.S. current will be applied. At the approach to a station the wagons will pass over a short gap in the conductor rails and brakes (which will be electrically released when the train is taking current and applied when the train is not taking current) will be applied. The next section of conductor rail will normally be "dead," and will be of such a length as to allow the wagon to come to rest, the brake remaining on.

In the case of a wagon which is required to stop at the station, a L.S. current will be applied to this brake section and the train will move to the station platform, and will finally be brought to rest owing to the application of the brakes when it reaches its sub-section of the station platform, the conductor rails of that sub-section having been made "dead" for its reception. In the case of a through train I.S. current would be applied to the brake section, and the wagon would run at this speed through the station, would pass over a short gap in the conductor rails, and then without a stop on to the sections of the track energized by H.S. current. In the event of its being possible to accept, without delay, either a stopping train or a through train, the braking section or a certain portion thereof would be energized with I.S. or L.S. current respectively before the train reached that section, in which case the train would merely be retarded down to the speed corresponding to the current applied, and would either pass up to the platform or straight through the station. A wagon will be dispatched from the station by making alive the conductor rails of the sub-section on which it has been standing with I.S. current, if it is being sent on to a main line, or with L.S. current for shunting operations.

Wagons will be moved into the sidings and brought to rest in certain sections in the same manner as at the platforms, and a device will be provided for automatically reversing the connections of the motors, when desired, just as they are coming to rest, so that they may move off in the opposite direction when current is applied to withdraw them from the sidings. Means will also be provided for holding the brakes off without applying driving current to the motors, so that the wagons may readily be coupled up to form two or three car trains. When coupled up in this manner it will be arranged that by means of a train cable and certain switches the shoes of the rear wagon only will collect current from the conductor rails, but the motors on all wagons will be operative and share in the driving of the train. This arrangement will overcome difficulties which would otherwise arise in dealing with both single wagons and trains at gaps, braking sections, and dead sections at the platforms and in the sidings.

It should here be made quite clear that it is not intended that the control of the wagons as they come to rest in, or pass through, the station should need the continuous attention of the switchman. The position and destination of each wagon will be notified to this officer, who, by means of small levers in the cabin, will set points for the particular route desired and will energize certain sections of the conductor rails with the appropriate current. The wagon will then come to rest at the proper section of the platform, or will run through the station without further attention. The operation of the points will be interlocked with the application of the current, and there will be a complete interlocking arrangement between the different routes.

The proposed system of control may be briefly described as being generally similar to the power-operated point and signal systems adopted for modern railway undertakings, but with the signal element replaced by the application of current to the track. It is considered that it is only by such a system of complete interlocking that a remote-control electrical railway of this scope can be safely operated.

Between stations the conductor rails will be divided into sections, and while running between stations and before coming within the control of the switchman the wagon will itself render each section "dead" as it leaves it, and will make it "alive" again on entering the next section but one, that is to say, there will always be a "dead" section between adjacent wagons or trains.

Means will be provided for indicating not only the position, but also the destination of approaching trains, and so enabling the switchman to arrange for their reception either separately or simultaneously as the case may be, being protected against mistakes by the interlocking arrangement which has been described above.

Possibly at a later stage a separate paper may be read on this railway and its equipment, as the problems which have presented themselves for solution have certainly proved very interesting and in many respects novel.

XI. Electric Trucks and Vans.

The electric railway is not the only direction in which the use of electric traction for postal purposes is being introduced. With a view to reducing human labour and the delays connected with double handling, trials are at present being made with an electric truck equipped with an Edison battery.* This truck, which weighs only about 25 cwt. including a load of 10 cwt., is intended for use more particularly at offices that are in close proximity to railway stations, and can ply between the sorting office and the mail vans, the control being sufficiently safe and flexible to meet the conditions of a crowded platform, while slopes as steep as 1 in 10 can be negotiated.

Trials of the truck, which is equipped with 42 B4 cells, have been carried out on level wood-block flooring (the wheels having solid india-rubber tyred wheels 15 in. diameter) over a rectangular course 824 ft. per circuit at full speed (5 to 7 miles per hour), and at about half-speed (3 to 4 miles per hour) over alternate circuits and with a stop at the end of each circuit, and the following results have been obtained :—

Total weight of truck, load, and driver...	26 cwt.
Voltage before run (half battery) ...	30 volts
Voltage after run (half battery)	20 "
Total number of journeys...	160 "
No. of miles...	25 "
No. of units used for charging	7·3 "
No. of watt-hours per ton-mile	225 "

Experiments are also being made with electrically-equipped vans for collecting purposes.

* *Electrical Review*, vol. 73, p. 342, 1913.

XII. Conclusion.

While the above examples do not exhaust the various applications of power for the Post Office, they will probably suffice for the purposes of this paper. Nearly all these applications involve the employment of electricity, without which many of the appliances could not have been devised or employed in the places where they are required.

The author wishes to express his thanks to the Engineer-in-Chief, Mr. Slingo, for permission to read the paper. He also desires to acknowledge the assistance which he has received in its preparation from Messrs. W. H. Powell, H. V. Cornish, J. R. Matthews, and E. H. Walters, who are closely associated with the work which has been described.

ELECTRICITY SUPPLY OF LARGE CITIES.

By Professor G. Klingenberg, Dr. phil.

(*Address delivered before* The Institution, *4th December*, 1913.)

Electricity is now universally acknowledged to be the most suitable form of energy supply for large cities, and apart from the convenience and reliability, its wide range of application makes it superior to gas, which 20 years ago had no competitor in this field. Although electricity was originally intended exclusively for lighting, its extensive application for power soon followed, and in many towns the power demand nowadays exceeds the lighting consumption. Electricity has introduced a radical change in the means of communication, by permitting the successful introduction of rapid transit systems (underground and elevated railways) which are regarded as indispensable in large cities at the present day. A further field has been opened in its application to heating and cooking. The fact that electricity, notwithstanding its obvious advantages, has hitherto been unable to drive its competitors entirely out of the field, is solely due to the difference in price for the same amount of energy, arising from the cost of electricity in some of its applications.

Any reduction in price therefore results in an increased use, and it may be said without exaggeration that there would be no demand for other forms of energy if all electric supply undertakings would fully recognize the advantages which our present-day knowledge and experience place at their disposal, and if they could rid themselves of the restrictions originally placed upon them in the supposed interests of the consumer, which restrictions are now very often found to be a hindrance to both consumer and producer.

It is the purpose of the present Address to explain the nature of these conditions and draw attention to those factors which would contribute towards a reduction in the cost of electricity and facilitate its more extensive employment.

With reference to existing conditions, I have confined myself to three examples which I consider to be typical. The material at my disposal enabled me to extend my investigations to details which will be of value when forming an opinion on the entire question. The cities selected are :—

Berlin—Berliner Elektricitätswerke,
Chicago—Commonwealth Edison Company,
London—the municipal authorities and authorized supply companies in and around London.

The figures are based on the following years : —

Berlin	1911–12
Chicago	1911
London	1910–11

Historical Development of Electricity Supply.

Berlin.

In Berlin the electricity supply began with the purchase and operation of generating sets by commercial undertakings solely for their own requirements, and without intention of selling energy to outside consumers. This system was found to be convenient as it was not necessary to lay conductors in the streets, and as complete independence of municipal authorities was possible. A number of these so-called "block stations" still exist, their combined output being estimated at nearly 40,000,000 kw.-hours per annum.

The Berliner Elektricitätswerke alone formed an exception in this respect ; they were intended from the outset to supply current to outside consumers. In their contracts of the years 1888, 1899, and 1907 they obtained the right to use the streets, etc., upon the condition that they supplied all the electricity required for any purpose within the city of Berlin. They were accorded permission to generate electricity in the interior of the city, and to supply current to the city from outlying power stations. They were further authorized to supply current outside Berlin, on the condition, however, that the city plants as well as those outside the city within a radius of 30 kilometres (about 20 miles) could be taken over by the city authorities upon the expiration of the contract (1915). In consequence of the permission granted to supply current within any desired radius of Berlin, the Berliner Elektricitätswerke were able to form a new supply area beyond the Berlin boundary, and to take financial interest in new undertakings. The tariffs are subject to the approval of the city authorities, who have decreed that the price at which the current is supplied must be reduced when the net profit exceeds 12½ per cent on the share capital. The city also participates in the profits, and receives 10 per cent of the company's gross income, and half the net profit after 6 per cent has been paid on the share capital up to M.20,000,000, and again half the profit left after paying

4 per cent above this amount. The sum paid out in this manner during the past financial year, for example, was M.7,184,000 (£350,000), which considerably exceeded the dividend paid on the company's share capital of M.64,100,000 (£3,150,000).

The development of the Berliner Elektricitätswerke may be seen from the following figures for the energy sold :—

1900–1	Energy sold	= 69,700,000	kw.-hours
1905–6	,,	= 126,200,000	,,
1910–11	,,	= 192,100,000	,,
1912–13	,,	= 244,300,000	,,

Although the city has formally notified the Berliner Elektricitätswerke of its intention to exercise its rights to take over the whole concern in 1915, no definite decision has yet been reached.

The system of feeders of the Berlin electricity supply, the power stations, sub-stations, and feeder circuits (three-phase cable 6,000/10,000 volts) are shown in Fig. 11. The distribution in Berlin itself is on the continuous-current system throughout, with the exception of the suburbs and a section of the city in the north, which are fed directly with three-phase current.

Apart from the Berliner Elektricitätswerke and the above-mentioned block stations a number of separate traction power stations exist, which supply energy to the underground railways and a part of the tramway system.

Chicago.

The Chicago electricity supply originated in a large number of small supply companies (approximately 36) which were amalgamated between the years 1892 and 1906 to form two large companies, viz. :—

The Chicago Edison Company,
and The Commonwealth Electric Company.

In 1907 these two companies were amalgamated under the title :—

The Commonwealth Edison Company.

All the small power stations have been shut down since then, and the whole supply is now obtained from four large power stations.

The concession extends over a period of 50 years, dating from the year 1897, and it stipulates the maximum rates to be charged by the company, and a payment of 3 per cent on the annual gross receipts to the city.

The development of the company may be seen from the following figures for the energy sold :—

1900	Energy sold	= 33,700,000	kw.-hours
1905	,,	= 93,000,000	,,
1910	,,	= 550,000,000	,,
1912	,,	= 712,000,000	,,

The sub-stations are fed with three-phase current at 9,000 volts, 25 cycles, and in part at 20,000 volts, 60 cycles. The distribution in the interior of the city is on the continuous-current system, while in the outlying districts three-phase current at a frequency of 60 cycles is adopted.

London.

If I understand the history of electricity supply in London correctly, it began, as in the case of Chicago, with a number of private companies. Their development was hampered, however, in the earlier stages by legal restrictions which limited the concessions to a period of 21 years and divided the electricity supply of the city into a number of districts corresponding to the administrative divisions, without taking into account the natural development of the distribution system. Every authorized supply undertaking was obliged to erect its own generating station and to lay out its own distributing network. An amalgamation of the different concerns was therefore out of question until in 1908 the original Act was modified by a new Bill. Since that time constant endeavours have been made to combine the numerous companies, to centralize the generation of energy, and to standardize the different distribution systems as far as possible.

Discussion of the Factors determining the Cost to Consumers.

It has already been mentioned in the introduction that the development of the electrical industry in large cities is chiefly dependent upon the price of electrical energy, and I now propose to discuss the factors which determine this price.

Cost of plant.—The specific cost of the plant, *i.e.* the cost per kilowatt installed, should be mentioned in the first instance. As each kilowatt installed is only capable of supplying a given number of kilowatt-hours, the increase of cost will be in proportion to the capital expenditure per kilowatt, provided that other conditions remain unaltered.

A distinction must be made here between the cost of the power station and that of the network. In the power station the cost per kilowatt decreases rapidly as the size of the generating sets increases, or the more the generation of energy is centralized in large power stations. For works with modern generating sets of 1,000-kw. capacity the installation costs are found to be approximately £15 per kilowatt, whereas for units of 20,000-kw. capacity they only amount to one-half of this sum. Bearing in mind that for large cities outputs of several hundred-thousand kilowatts are required, units of less than 20,000-kw. capacity are obviously unsuitable and too expensive for this purpose, and the installation of 30,000-kw. sets appears to be fully justified. In consequence of this development the specific cost of power stations has fallen in about 10 years to nearly a quarter of its former value.

The conditions are not so favourable, as a rule, for the network. When the amount of energy that can be transmitted is increased by using cables of larger sectional area, the economic limits are soon reached, since the permissible specific load on a conductor, and therefore its effective utilization, decrease as the sectional area is increased. On the other hand the idea of extended centralization seems to have the reverse effect on the cost of the network, since this cost is increased by using longer feeder cables without any direct gain being secured as regards the network itself.

It is, nevertheless, also possible to economize on the capital outlay of the distribution system. In this connection the use of higher working voltages should first be mentioned. The customary feeder cables for pressures

of 6,000 to 10,000 volts no longer meet present-day requirements in large cities. The additional cost of transformation in the power station when the cable pressure exceeds 10,000 volts is counterbalanced, even in the case of short distances, by the saving effected in the cables. Whenever extensions are contemplated, pressures of 20,000–30,000 volts should be adopted, even should this entail a further transformation at some points where stations with different pressures have to be connected up.

At the above pressures it is possible to transmit outputs of more than 10,000 kw. through one cable. The cost of the feeder cable is reduced to about 2s. 6d. per kilometre per kilowatt transmitted, so that this part of the installation cost becomes of less importance for the short distance over which the energy has to be transmitted in cities.

A further means of reducing the cost of the network is found in the conversion of the entire system to a uniform alternating-current system, by laying ring mains and by interconnecting the various sections of the city.

Charges on capital.—The determination of the price for the current should be preceded by the fixing of the rate for capital charges, which must be regarded as the minimum for the prosperous development of the undertakings in question. In many instances the low rate of interest forms an obstacle when new capital is required; it prevents the concern from adopting progressive measures for improving the economy of the plant, and indirectly keeps the cost of the current unnecessarily high. On the other hand, it will be agreed that an undertaking which has to make use of public streets and thoroughfares, and is granted certain privileges by local authorities, is under an obligation to consider the interests of the general public in addition to its shareholders' interests.

The demands of the authorities, however, have unquestionably on many occasions exceeded reasonable limits, and by hampering the entire undertaking have impeded rather than assisted public interests. In my opinion, interest at 6–8 per cent on the value of the plant represents for undertakings of this kind the lowest limit which would ensure a favourable market for the company when it requires further capital. As regards the sinking fund and other reserves, an average figure of 3–4 per cent seems to be reasonable for power stations, sub-stations, and distribution system; for long-distance transmission lines and feeder cables in which the conducting material (copper) represents a high percentage of the total value, about 2 per cent may be sufficient. I have therefore based the following calculations upon uniform capital charges of 10 per cent for power stations, sub-stations, and distribution system, and 8 per cent for transmission lines and feeder cables, and I have called the current prices calculated from this basis "normal prices."

There are two ways of dealing with the control by the municipal authorities or by the public of the surplus profits above the agreed normal rates; namely, either by direct participation in such surplus amounts or by the reduction of the price at which the current is supplied under normal conditions. The latter form is doubtless the more appropriate, since consumers receive the benefit of the surplus direct, and reduced prices attract new consumers, so that both parties derive an advantage. Naturally a reduction in price should not be based upon the results of a single year's working.

Cost of operation.—The direct operating costs affecting the price of electricity chiefly consist of the following items: Coal, stores, wages, repairs, taxes, insurance, and general expenses such as wages, management, office costs, etc. The cost of the losses between the power station and the point of consumption must also be included here.

The costs of generation are directly dependent on the size of the power station, or on the size of the generating sets. Power stations with units of 20,000-kw. capacity consume only about three-quarters of the quantity of coal at full load compared with works in which modern 1,000-kw. sets are installed, and only half or even less of that consumed in older power stations with units of this size. The operating staff required depends chiefly upon the number of machines and not upon their size, this being more particularly the case in modern power stations in which human labour is replaced wherever possible by automatic machinery. Therefore labour costs are far more favourable in plants with large generating sets. The same applies to the sums required for repairs, stores, and general expenses.

The operating costs for the network are not directly dependent upon the size of the undertaking. By subdividing the distribution system in accordance with the best engineering practice, by simplifying the organization and by standardizing the plants, economies can be effected. Here again attention should be drawn to the superiority of the alternating-current systems over the mixed systems.

Transmission losses.—The transmission losses, which in the old plants amount to about 20 per cent of the energy generated, and thus represent from 10 to 15 per cent of the selling costs, can unquestionably be reduced to half this figure with the enlargement and standardization of the plant, this being more particularly the case in view of the fact that lower generating costs also reduce the cost of the losses.

Utilization of the plant.—A comparison between different undertakings and the prices at which they sell their current is only possible when the extent of their utilization is known.

By the term "utilization" I mean the ratio of the kw.-hours sold within a given period (usually taken as a year = 8,760 hours) to that number of kw.-hours which the plant would have been capable of generating if all the machines had been running constantly at full load during this period.

The utilization of the plant can thus be expressed by the following formula—

$$n = \frac{\text{kw.-hours sold per annum}}{\text{installed capacity of plant} \times 8760} = \frac{\text{average load sold}}{\text{installed capacity}}$$

This term has been in use for some years on the Continent. I have called it the "utility factor" (n) of the plant. The following particulars will show that the use of this factor affords valuable assistance in arithmetically following up the somewhat intricate relations between the cost of the current and the utilization of the plant.

In determining these functions it is necessary to ascertain the energy costs (or proportionate energy costs) both for the entire plant and parts of it when working permanently at full load, these values being characteristic and practically constant for each individual plant.

With regard to the capital charges (interest, dividends, sinking fund, etc.) this value (A_z) is obtained by dividing

the annual interest by the product of the total plant capacity and the number of hours per year. If, for example, the capital charges are found to be k_z shillings and the total capacity of the plant L kilowatts, the characteristic value for the capital charges is given by the formula—

$$A_z = \frac{k_z}{L \times 8760} \text{ shillings per kw.-hour sold.}$$

As on the other hand the energy costs for capital charges with any desired utilization can be expressed by the formula—

$$K_z = \frac{k_z}{\text{kw.-hours sold per annum}} \text{ shillings per kw.-hour sold,}$$

by dividing the above two formulæ we find that—

$$\frac{A_z}{K_z} = \frac{\text{kw.-hours sold per annum}}{L \times 8760} = n,$$

which is equal to the value defined above as the utility factor. Hence the relation between the utilization and the ratio of the capital charges to the energy costs is represented by the formula—

$$K_z = \frac{1}{n} \times A_z \text{ shillings per kw.-hour sold} \quad . \quad . \quad (1)$$

In a similar manner it can be shown how the direct-operating costs (coal, repairs, wages, etc.) depend on utilization. Here, however, the characteristic costs per kw.-hour for full load are partly independent of utilization. The relation between utilization and operating costs can then be found from the expression—

$$K_b = \frac{1}{n} \times a_b + b_b \text{ shillings per kw.-hour sold} \quad . \quad (2)$$

It can be shown that the value a_b represents those costs which would be entailed if the plant had to be kept ready for service without supplying useful energy; in other words a_b are the no-load costs. The recognition of this fact enables the values a and b to be separated. Thus the proportion of the running costs to the selling price of energy can be determined for any utilization in accordance with Equation 2.

In determining the value a (no-load consumption) for the fuel of the power station, the time during which each set is run must be taken into account. It can be shown that this is done with sufficient accuracy for practical purposes by making the following modification of Equation 2:—

$$K_k = \frac{n+1}{2n} \times a_k + b_k \text{ shillings per kw.-hour sold} \quad (3)$$

The transmission losses may be expressed by a similar formula on the assumption that the copper losses, which really vary as the square of the load, are proportional to the latter. This simplification appears to be permissible, since the cost of the losses only forms a small part of the total costs. The losses are thus found to be—

$$V_{kw} = \frac{1}{n} a_{kw} + b_{kw} \text{ kw.-hours per kw.-hour sold} \quad . \quad (4)$$

where a_{kw} = no-load losses (iron losses of converters, transformers, etc.), and b_{kw} = copper losses of transformers, cables, etc.

In order to obtain the cost of the losses, the above value must be multiplied by the price per kw.-hour generated (including profit and interest) found from the Equations 1 to 3.

The total selling cost per kw.-hour is thus found to be equal to the sum of—

- Proportion of costs referred to the power station including capital charges.
- Proportion of costs for the transmission and distribution losses including capital charges.
- Proportion of costs for the operation of the transmission system including capital charges.

And they can be represented by a single equation—

$$K = \frac{1}{n} \times a + \frac{1}{n^2} \times a_1 + b \text{ shillings per kw.-hour sold} \quad . \quad (5)$$

which is called the costs characteristic for the entire plant. With this equation one can ascertain the average energy costs for the entire plant, and one can also graduate the prices payable for the various classes of consumption in correct steps as soon as their individual influence upon the utility factor is known.

Determination of the utility factor.—In view of the importance of the utility factor in connection with the selling price of the current, I now propose to discuss those points which determine the value of this factor.

One of the first points to be considered in this respect is the load factor, m, which is given for the entire plant by the ratio between the average load of the power station and the peak load, and can be expressed by the formula—

$$m = \frac{\text{kw.-hours generated per annum}}{\text{peak load} \times 8760} = \frac{\text{average load}}{\text{peak load}}.$$

This value is proportional to the utility factor.

Whereas in small plants irregularities in the consumption are perceptible in the power station, and the load factor in such stations may be affected by a single consumer, in large stations load fluctuations are equalized as the size of the plant increases. It is therefore possible to determine the form of the load curve, and therefore load factor, for large plants with sufficient accuracy from the outset, provided the general nature of the consumption is known. Leaving out heating and cooking, three principal classes of consumption remain—namely, power, traction, and lighting. Each of these classes possesses a special load curve, which is similar in all large cities and only varies for lighting according to the latitude. Whereas the power and traction load curves remain approximately constant throughout the whole year (with the exception of Sundays), the lighting load varies according to the season, so that both the average annual load and the maximum load in winter must be known in order to determine the load factor.

Such characteristic load curves for power, traction, and lighting are shown in Fig. 1. The maximum load in all three cases is assumed to be 100, the day of 24 hours being

divided into 100 parts, beginning at midnight. The load factors are—

Light	...	approx. 18 per cent (Sundays excluded)
Power	...	„ 50 „ „ „
Traction	...	„ 50 „ „ „

From these standard curves we can obtain the resultant load curve and also the resultant load factor "m" for any desired combination of lighting, power, and traction consumers.

As examples such combined load curves are set out in Figs. 2 and 3, the first showing a lighting and power curve, and the latter a lighting, power and traction curve. In order to include all conditions which have to be taken

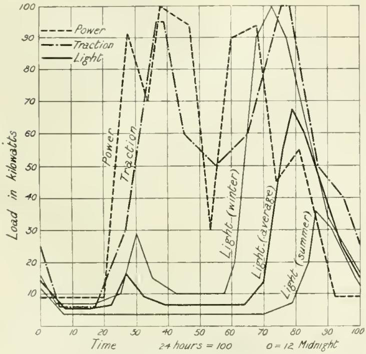


FIG. 1.—Daily load diagram of large power stations.

Peak load = 100.

	Load factor
Power	= 50 %
Traction	= 50 %
Light:	
Summer	= 8 %
Winter	= 30 %
Average ...	= 18 %

into account and which are affected by various combinations of consumers and the degree of centralization, a further diagram, Fig. 4, has been drawn, based on the load curves given in Fig. 1. From this diagram the resultant load factor can be read off directly as soon as the percentages for power, traction, and lighting are known. If, for instance, the kw.-hours consumed comprise 20 per cent lighting, 12 per cent power, and 68 per cent traction (this approximately resembles the conditions in Chicago for 1911) then the resultant load factor lies at the intersecting point of the curve—

$$r_k = 12/20 = 0{\cdot}6,$$

with the abscissa value—

$$r_b = 68/(12 + 20) = 2{\cdot}13,$$

according to which a resultant load factor of 40 per cent for the above relationship may be expected, which approximately corresponds to the actual value obtained, namely 41 per cent.

This diagram demonstrates the important fact that by superimposing power and traction curves (top curve $r_k = \infty$) the load factor may be improved only by 2 to 3 per cent, while on the other hand by combining the power and traction supply with a lighting load of about 12 per cent, the resultant power factor is not materially decreased. Considering that in large cities 12 per cent of the total is not far from the actual requirements for

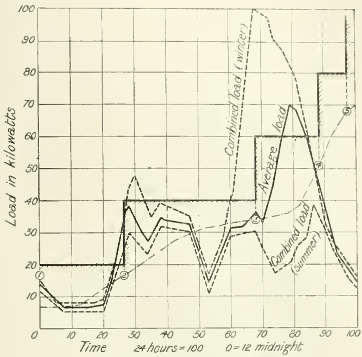


FIG. 2.—Daily load diagram or running time of machines.

Assumption: Light, 50 % of total output.
Power, 50 % „
Traction, nil.
Installed: 6 sets, output of each, 20 % of peak.
Stand-by: Permanent, 20 % of peak.
Overload, 4 hours, 25 %.

	Summer	Winter	Average
Load factor	21·0 %	38·8 %	29·1 %
Utility factor	17·5 %	32·3 %	24·3 %

Consumption of fuel: $1{\cdot}58\, a_w + b_w$ metric cal. per kw.-hour.

lighting, this means that it will be possible in future to generate (not to distribute) the current for lighting at practically the same price as for power and traction.

Next to the load factor, the efficiency of the network has to be taken into account in determining the utility factor. This efficiency is expressed by—

$$\eta = \frac{\text{kw.-hours sold}}{\text{kw.-hours at feeder busbars}}.$$

This value is again in direct proportion to the utility factor.

So far as the selling price of the current is concerned, this means that the improvement of the distribution efficiency not only produces a saving in the cost of the

losses, but also (through the increase in the utility factor) causes a reduction of the remaining costs.

The third point is the amount of stand-by, the utility factor being inversely proportional to the capacity of the stand-by. Although it is difficult to state any rule for the percentage of stand-by to total plant, this percentage can be reduced with the increase in size of the total plant. This is mainly due to the fact that in the smaller stations the load curve is subject to more violent fluctuations. Therefore, in addition to stand-by for overhauling and repairs, reserves are required to meet such variations in load. The stand-by factor is—

$$r = \frac{\text{installed output}}{\text{peak load in station}},$$

where the decimals indicate the percentage in spare plant.

The relation between utility factor, load factor, distribution efficiency, and stand-by is then given by the formula :—

$$n = m \times \eta \times \frac{1}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

By inserting this value in Equation 5 for the costs characteristic of the plant, the influence of any of the above factors upon the costs can be ascertained.

In view of the important effect on the utility factor resulting from a combination of various classes of consumers, a few remarks should be made here bearing upon the practical possibility of such a combination.

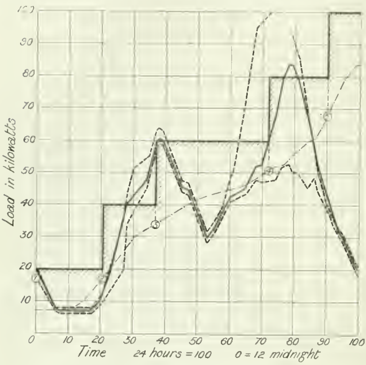


FIG. 3.—Daily load diagram for running time of machines.

Assumption : Light, 25 % of total output.
Power, 25 % „
Traction, 50 % „
Installed : 6 sets, output of each, 20 % of peak
Stand-by : Permanent : 20 % of peak.
Overload : 4 hours, 25 %.

	Summer	Winter	Average
Load factor	33·8 %	45·8 %	39·3 %
Utility factor	28·2 %	38·2 %	32·8 %

Consumption of fuel · 1·43 $a_n + b_n$ metric cal. per kw.-hour.

In the early stage of electricity supply separate feeders and even separate generators were used for power and lighting. While in the meantime this practice has been abandoned, it is still usual in large cities at the present day to separate the supply for traction from that for lighting and power, or to provide special power stations and networks for traction. It must be pointed out that this method, which might be justified with a number of small plants, can only be condemned in the case of large power stations, since, as has been shown in Fig. 4, owing to the inferior utilization, this entails a waste of capital and a permanent disadvantage to consumers.

No disturbances are likely to arise from sudden current rushes caused by traction loads, as these are easily compensated for in large power stations. The statement made by supporters of separated systems that the traction demand is sufficiently heavy to justify a special plant is fundamentally wrong, since they overlook, first, that practically no traction station has yet reached the economical limits as regards size, and secondly, that the point of chief importance is not the reduction of costs for the traction demand, but of those for lighting and power supply, as shown above in connection with Fig. 4.

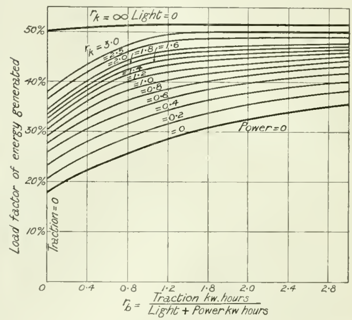


FIG. 4.—Load factor in large cities for varying ratio of light, power, and traction.

Based on lighting load factor = 18 %
power load factor = 50 %
traction load factor = 50 %

$$r_k = \frac{\text{Power kw.-hours}}{\text{Light kw.-hours}}; \quad r_b = \frac{\text{Traction kw.-hours}}{\text{(Light + Power) kw.-hours}}.$$

EXAMPLES TAKEN FROM EXISTING PLANTS.

It is now proposed to give a summary of the operating conditions in the Berlin, Chicago, and London plants, thus providing an opportunity for checking the foregoing statements by applying them to practical conditions.

For this purpose the material at disposal has been tabulated in such a manner that the items relating to the three plants can be directly compared with one another. The author has also succeeded, by making some assump-

tions, in determining the relation between working costs and utility factor, and has thus obtained the equation for the costs characteristic of all three plants. This conversion appeared to be necessary since the plants in question have a totally different kind of consumption, and therefore work with different utility factors. Any attempt to draw general conclusions on the advantages of one system over the other is bound to be misleading, unless this is done. Moreover, this analysis seemed to be the only means of obtaining a positive indication of the influence which the difference in centralization of the three plants exercises upon the working and energy costs.

Comparison of Works Statistics in Berlin, Chicago, and London.

The comparative data have been summarized in Tables I to III of the Appendix.

The following remarks are made by way of explanation :—

The energy consumption per head of population cannot be compared directly from the figures given, since both in London and Berlin the energy is generated in special traction power stations, and in the case of Berlin that generated in block stations must also be included. Unfortunately, reliable data in this connection could not be secured ; the figures for the years in question may be assumed, however, to be approximately as follows :—

Current consumption in kw.-hours per head of population :—

Chicago	310 kw.-hours
Berlin	170 ,,
London	110 ,,

These figures, although somewhat approximate, show that in the two latter cities the consumption should be capable of a considerable increase, even assuming Chicago to have reached the point of saturation, which, in the author's opinion, is not the case.

It is a striking fact that in London the generation of energy is split up amongst a large number of small stations, whereas Chicago stands pre-eminent as regards centralization.

The proportion of the average peak loads in the different stations is approximately as follows :—

London	1
Berlin	5
Chicago	10

In order to secure a basis of comparison for the real estate value of the plant, the author has in all cases subtracted the reserves, sinking funds, and all cash balances so far as they can be obtained from the balance sheets, with the exception of the working capital.

The installation cost per kilowatt is then found to be approximately as follows :—

Berlin = 950 shillings per kilowatt installed
Chicago = 1,200 ,, ,, ,,
London = 1,460 ,, ,, ,,

It is noticeable that the cost per kilowatt of the Chicago plants is about 25 per cent higher than that of the Berlin plants, although the former are of nearly double the capacity. This may be attributed to a certain extent to the cost incurred in buying up the competitive companies, the power stations of which have been put out of commission. This sum amounts to about 9–10 per cent of the total cost. The explanation of the difference which then remains between the Chicago and Berlin costs may possibly be sought in the different method of design, and in the more expensive living conditions prevailing in the United States. It is impossible, therefore, to draw any conclusions regarding cost per kilowatt.

A comparison is, however, possible between Berlin and London, where methods of design and living conditions differ less. From such comparison it will be seen that the total cost per kilowatt installed, with power stations of about 5,000 kw., is approximately 50 per cent greater than for power stations of about 25,000 kw. ; this difference appears to be still greater, namely 80 to 90 per cent, when the costs of the power stations alone are compared. The ratio of the cost of the power station to that of the network (including meters) is also noteworthy ; for Chicago and Berlin it is approximately 40 : 60, and for London 45 : 55. It can thus be seen that the cost of the power station decreases as the size of the plant increases. This matter will be referred to again further on.

With regard to the consumption, the three plants can be characterized as follows :—

Chicago : traction load predominating (approx. 70 per cent).

London : lighting load predominating (approx. 60 per cent).

Berlin : power, lighting, and traction loads in a more even ratio.

The Chicago load factors correspond to the values given in Fig. 4, because the conditions for a combined service of lighting, power, and traction appear to be fulfilled. Berlin remains somewhat behind these values in consequence of partial separation of different services and the influence of Sundays upon power consumption. London is considerably below the other two cities as regards the utilization of its plant, owing to its predominating lighting load. Fig. 4 shows that in London the load factor cannot be improved appreciably by centralization ; what is necessary is to alter the nature of the consumption.

As reserve factors for power stations are altered with each extension, especially in the case of large units, it is advisable to take the average for a considerable number of years. Thus the figure of 11 per cent for Chicago seems too low, and the figure of 45 per cent for Berlin too high, while for London, where the largest machine unit is about 5,000 kw., the value of 61 per cent should be approximately correct. I consider the load factor should not largely influence the percentage of reserves. What affects the spares most is the size of the whole plant.

In view of such considerations the following reserve factors (r) appear to meet the normal requirements of large cities :—

With a maximum load on individual stations of 30,000 kw., $r = 1{\cdot}25$.

With a maximum load on the separate stations of 15,000 kw., $r = 1{\cdot}4$.

With a maximum load on the separate stations of 3,000 kw., $r = 1{\cdot}6$.

It is assumed that each power station is equipped with at least one complete generating set as a stand-by.

Owing to the fact, expressed in Equation 6, that the utility factor depends not only on the load factor but also on the network efficiency and the reserve factor, the utility factors of the three plants differ to a greater extent

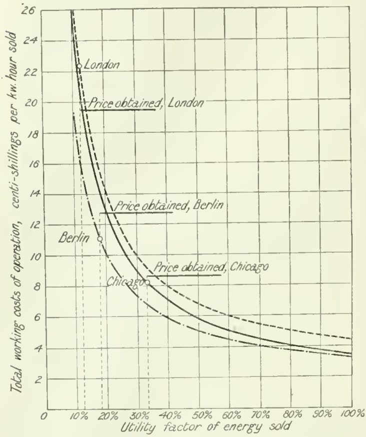


FIG. 5.—Total working costs per kw.-hour sold, including 10 % for capital charges (interest, sinking fund, etc.).

	Berlin, 1911–12	Chicago, 1911	London, 1910–11
Capital per kw. installed	949·62s.	1,200·36s.	1,459·00s.
Plant installed in kw.	137,000	221,700	298,400
Peak load in kw.	94,600	199,300	185,500
Energy sold in kw.-hours ...	$216·3 \times 10^6$	$640·0 \times 10^6$	$319·2 \times 10^6$
Load factor of energy generated	33·1 %	41·0 %	24·9 %
Utility factor of energy sold ...	0·180	0·330	0·122
Overall efficiency $= \frac{\text{Energy sold}}{\text{Energy in coal}}$	9·7 %	approx. 7·6 %	approx. 5 %

than would be expected from the nature of the consumption alone. The ratios are shown in round figures as follows:—

London.	Utility factor, 12 % ;	Load factor, 25 %
Berlin.	" 18 " ;	" 33 "
Chicago.	" 33 " ;	" 41 "

These results, together with the remaining items in Tables I and II, enable their dependence upon the utilization to be determined, and by means of the costs characteristic thus found the working conditions can be compared on an equal basis.

The results of these calculations are shown graphically in Figs. 5 to 8; Fig. 5 shows the total costs characteristic of the plant, while Figs. 6, 7, and 8 give the separate costs for generating, network losses, and network operation. The equations for these costs are put together in Table IV.

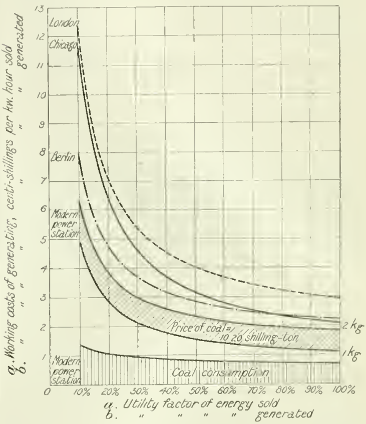


FIG. 6.—Working costs of power station as part of total costs (kw.-hours sold), including 10 % for capital charges.

Comparison with costs of generating in large modern works.
Cost of coal: 10–20s. per ton.
Heat value of coal: 7,000 metric cal. per kg.

	Berlin, 1911–12	Chicago, 1911	London, 1910–11
Capital of power station per kw. installed	355·93s.	477·10s.	662·00s.
Energy generated in kw.-hours ...	274×10^6	684×10^6	405×10^6
Load factor of energy generated	33·1 %	41·0 %	24·9 %
Utility factor of energy generated	0·228	0·352	0·155
Utility factor of energy sold ...	0·180	0·330	0·122

The following particulars will explain the above calculations, and the assumptions which had to be made in certain instances where statistics were not available.

All costs include the capital charges, and in all three cases the normal rate of 10 per cent referred to above has been taken. Further, Items Nos. 38 and 39 in Table III, viz. current purchased and the special expenses for the Berlin and Chicago works, are omitted.

To allow the operating costs, Items 32 to 41, Table III, to be separated into power station and transmission costs,

it is assumed that the values in column 4, Table V, express this relation at full load and equal installation costs. These are then modified in columns 5 to 7 by taking into account the ratio of the installation costs for the power stations to those for the distribution system (Items 9 and 10, Table II). The items were further divided into costs which are dependent or not dependent upon utilization (values *a* and *b* of the costs characteristic equations) in accordance with the percentages shown in columns 8 and 9, Table V. Notwithstanding the uncertainty of these figures, it can be assumed that the final results are sufficiently in accordance with the actual values, since inaccurate assumptions may compensate one another to a certain extent, and the division of the main items, namely the capital cost and fuel, can be regarded as correct.

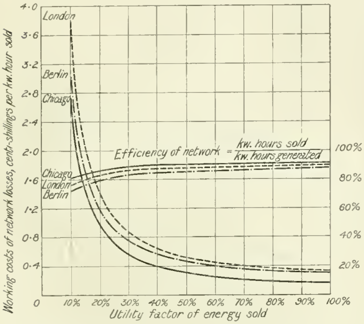


FIG. 7.—Working costs of network losses as part of total costs (kw.-hours sold), including 10 % for capital charges.

	Berlin, 1911–12	Chicago, 1911	London, 1910–11
Energy sold in kw.-hours ...	216·3 × 10⁶	640·0 × 10⁶	319·2 × 10⁶
Utility factor of energy sold ...	0·180	0·330	0·122

The actual utility factors, Item 23, Table III, are indicated in Fig. 5 by a circle. They therefore represent the "normal price" of the current, *i.e.* the price at which the works should earn a gross interest of 10 per cent on their capital, neglecting any special sums to be paid to the authorities.

The prices indicated in Fig. 5 by a horizontal line represent selling prices actually obtained by the works during the year in question (after deducting special expenses), and therefore permit a direct comparison with the normal value.

I may mention that in this address I have based my calculations upon the average selling prices throughout, and have ignored the division of the same into various classes of consumption, as this involves the question of tariffs, which does not come within the scope of the present subject.

RESULTS OF COMPARATIVE CALCULATIONS.

From these costs characteristics in Figs. 5 to 8 it will be seen that as regards total costs the Berlin works, notwithstanding their smaller power stations, work more economically than those in Chicago, while the costs of the London works are the least favourable. Nevertheless, the actual energy prices (based on equal utilization for all three plants) are approximately the same. The reason for this is that the selling price in London is about 13 per cent lower and in Berlin about the same percentage higher than the "normal" value.

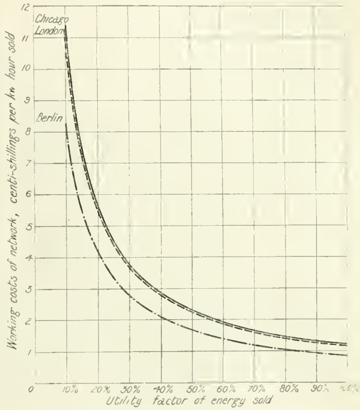


FIG. 8.—Working costs of network as part of total costs (kw.-hours sold), including 10 % for capital charges, and excluding costs of electric losses.

	Berlin, 1911–12	Chicago, 1912	London, 1910–11
Capital of network per kw. installed	593·69s.	723·26s.	797·00s.
Energy sold in kw.-hours	216·3 × 10⁶	640 × 10⁶	319·2 × 10⁶
Utility factor of energy sold	0·180	0·330	0·122

The relatively high working costs in Chicago, as compared with those in Berlin, are due in my opinion chiefly to the higher cost of the plant (Item 11, Table II) and the higher wages and salaries. Moreover, the Berlin plants show a decided superiority in fuel consumption, although this is counterbalanced by the appreciably higher prices for coal (see Items 24–26, Table III).

The importance of the utility factor for all three plants will be recognized from the form of the costs characteristic. The curves show that within the values for this factor of 10 to 30 per cent, the selling price can be reduced by more than 3 per cent for each advance of 1 per cent made in

utilization, without necessitating extensions or other alterations to the existing plant.

In order to gain some idea of the economy obtainable by the application of present-day experience, I have shown in Fig. 6 the characteristic for the generating costs in a large modern power station with machine units of 20,000 kw., based on coal prices between 10s. and 20s. per ton.

The lower vertical hatched section shows the coal consumption in a generating station of this kind, and simultaneously the costs for the same at a price of 10s. per ton. The area between the two hatched sections gives the generating costs, exclusive of coal but including 10 per cent capital charges. The comparison of the actual values obtained with those obtainable shows that with the same utility factor the generating costs in London, for example, could be reduced to less than one-half of what they are now.

A comparison on the same lines for the remaining operating costs (transmission) cannot very well be made owing to the divergency of conditions in the distribution systems. I nevertheless consider the superiority of Chicago (efficiency curves, Fig. 7) to confirm the opinion that a combination of the supply, and particularly a conversion to a pure alternating-current system, enables the cost of losses and distribution to be reduced considerably.

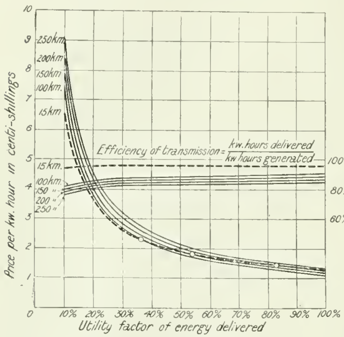


Fig. 9.—Comparison of total working costs between local and distant power stations with overhead line transmission.

Price per kw.-hour delivered at main feeding points of 20,000-volt ring system and including capital charges of 10 % on power stations and sub-stations, and 8 % on overhead line and cables.

	Distant Power Station	Local Power Station
Distance from centre ...	100 250 km.	Approx 15 km
Transmission	Main = overhead at 100,000 volts Local = cable at 20,000 volts	Cable, 20,000 volts
Cost of coal	7s. per ton	10·5s per ton
Heat value of coal ...	7,000 metric cal. per kg.	7,000 metric cal. per kg.

Application of the above Deductions to Existing Plants.

The foregoing outlines the chief points to be considered in large cities. We will now endeavour to find means for applying these principles to existing conditions.

In going over the results of the investigation of existing plants it will be noticed that the working costs for the network (Fig. 8) differ only slightly and form a relatively small part of the total working costs.

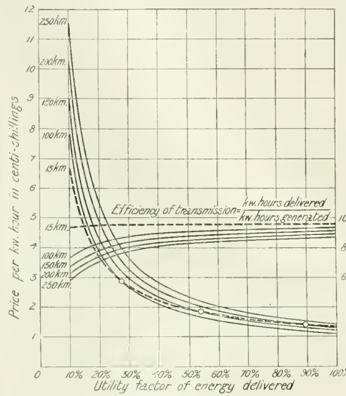


Fig. 10.—Comparison of total working costs between local and distant power stations with cable transmission.

Price per kw.-hour delivered at main feeding points of 20,000-volt ring system, and including capital charges of 10 % on power stations and sub-stations, and 8 % on cables.

	Distant Power Station	Local Power Station
Distance from centre ...	100 250 km.	Approx. 15 km.
Transmission	Main = cable at 100,000 volts Local = cable at 20,000 volts	Cable, 20,000 volts
Cost of coal	7s. per ton	10·5s. per ton
Heat value of coal ...	7,000 metric cal. per kg.	7,000 metric cal. per kg.

The saving to be expected here is small, because the greater part of the working costs consists of capital charges (see Table IV, Item 2).

A glance at the generating costs of the existing power stations (Fig. 6), and a comparison of the same with the values obtainable, distinctly shows that an effective way of improving the conditions would be to replace the existing power stations by large modern plants. This procedure, together with better utilization, would mean a saving of 30 per cent with a relatively small extra capital expenditure.

If, for example, all the existing power stations in London were shut down and large new stations took their place, a

saving could be effected of about 40 per cent on all working costs, at an increase of the total capital now invested of less than 20 per cent.

At this point a further possibility of reducing the working costs should be mentioned, which specially applies to large power stations and is dependent upon the site. This consists in a saving of coal costs by building the station in the immediate vicinity of coal-pits, and transmitting the energy through overhead lines or cables. It will be seen at once that this measure promises advantages wherever high coal freights prevail and where it is possible to use extra capital expenditure. This means, according to the deductions arrived at above, that as great a proportion as possible of the existing stations with high working costs are to be replaced by a large modern power station, without any outlay on altering the existing distribution systems. Obviously these conditions are best fulfilled by those concerns which are to-day generating alternating current at the same periodicity.

From the statistics of the year 1910–11 it can be seen that during this time some 25 electricity works in and around London supplied alternating current at 50 periods,

Fig. 11.—Feeding system of the Berliner Elektricitätswerke.

poor coal and obtain a good utilization of the transmission line.

Instead of firing the boilers with the coal direct, advantage may be taken under certain circumstances of the experience in the extraction of its valuable by-products such as nitrogen, tar, oils, etc.

Numerical Examples.

I have worked out an example based on the conditions prevailing in London. Naturally I cannot claim perfection for this scheme, as some of the initial values have had to be assumed, but I believe that, notwithstanding this uncertainty, the results meet the case.

The method I followed is based on the desire to achieve a maximum improvement in working costs with a minimum and represented altogether an installed capacity of 126,000 kw. Amongst these there are three concerns with more than 13,000 kw. capacity, totalling 46,000 kw.

These three stations, which are probably of a later date, show a relatively high economy, their immediate replacement is therefore unnecessary. The first step would then consist in providing a new power station having a capacity of 80,000 kw. to replace the 22 smaller stations, and in connecting their systems—which I assume to be distributed more or less uniformly—to a common network.

The interconnecting system would be laid out in a manner similar to the system adopted in Berlin for the recent extensions (see Fig. 11, 30,000-volt cable). Several ring mains would be run concentrically round the centre of the city, and the distance between rings would vary

according to the density of consumption. These ring mains would be duplicated in case of extensions and connected to one another by diagonal feeders.

In order to obtain an idea as regards the length and the cost of the cables, I have drawn in a system of this kind (Fig. 12) diagrammatically on a map of London, making due allowances for the increasing density of supply (shown by the closeness of the hatching) and the possibility of connecting up all the existing companies to the system. On the assumption that the total output of about 80,000 kw.

Twenty-five stations with an installed transformer capacity of 80,000 + 25% = 100,000 k.v.a. would be connected to the ring mains.

The new generating station is assumed to be situated within a distance of 15 km. (10 miles) from the centre of the city on a site of 50 ha. (130 acres).

Ten 20,000-volt cables, with the same dimensions and carrying capacity as the ring mains, would connect the latter to the power station. If the average length of the cable between the power station and the feeding points

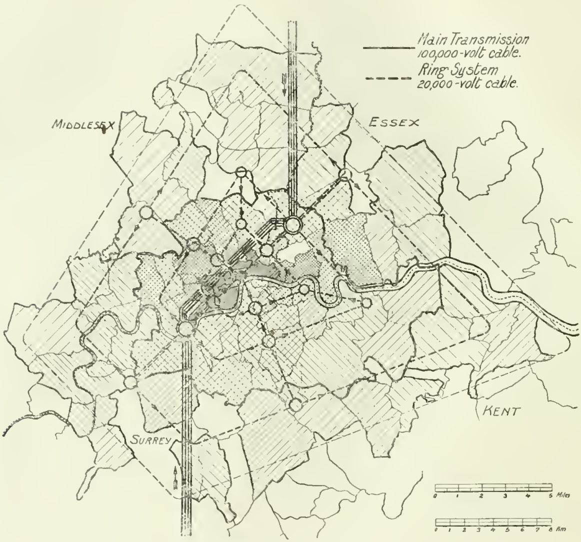


FIG. 12.—Assumed diagram of London Feeder System.

is to be distributed I consider that three ring mains, each consisting of one single three-phase cable, 3 × 150 sq. mm. (3 × 0·235 sq. in.), capable of transmitting 10,000 kw., should be sufficient. With this arrangement each of the stations belonging to the outer ring will be fed by at least two cables, while the cables laid diagonally provide for the necessary greater cable reserve in the interior of the city. I estimate that a ring system in accordance with the diagram shown in Fig. 12 will suffice for the distribution of 150,000 kw., showing that there is ample provision for further connections.

The total length of the cables would be approximately 250 km. (155 miles), allowing 15, 20, and 30 per cent for deviations from the straight line.

is assumed to be the same as the distance of the power station from the centre of the city, an additional allowance of 20 per cent being made for following streets, the total length of the cable would be 180 km. (110 miles).

The maximum losses in this cable would be approximately as follows:—

180 kw. dielectric losses;
3,240 kw. copper losses;

thus the characteristic for losses can be expressed approximately by—

$$\frac{1}{n} \times 0{\cdot}0023 + 0{\cdot}0428 \text{ kw.-hours per kw.-hour supplied.}$$

On the above assumptions the costs work out as follows—

A. *Estimate*—

1. Power station 83,000 kw., including transformers, switch-house and auxiliary buildings, @ 170s. per kw.
Extra for site, pile foundations, pumping plants, labour, etc., @ 40s. per kw. Shillings.
Total 17,430,000

2. Feeder cables 180 km. 20,000-volt 3×150 sq. mm. section, including laying, @ 27,800s. per km.
Total 5,000,000

3. Ring cables, 250 km., 20,000 volt 3×150 sq. mm. section, including laying, @ 31,000s. per km.
Total 7,750,000

4. Sub-stations: 25 with stationary transformers. Total capacity, 100,000 k.v.a., allowing for the partial use of existing building and sites, @ 40s. per k.v.a.
Total 4,000,000

Total cost 34,180,000
or 427·25s. per kw.

B. *Operating costs for the new plants.*—

Capital charges—
Power station and sub-station 10 per cent
Cable ... ... 8 „
Coal—
Price per ton ... ... 10s. 6d.
Calorific value per kg. 7,000 cal. (12,600 B.Th.U. per lb.)
Utility factor for all parts based on full load 80,000 kw.

Operating costs, including capital charges, are then calculated as follows :—

1. Power station $K_c = \frac{1}{n_{80}} \times 0·479 + 0·733$ centi-shillings per kw.-hour generated.
2. Feeder cables,
(*a*) Losses $V = \frac{1}{n_{80}} \times 0·0023 + 0·0428$ kw.-hours per kw.-hour supplied.
(*b*) Cost of losses $K_v = V \times K_c$ centi-shillings per kw.-hour supplied.
(*c*) Operating costs $K_{sp} = \frac{1}{n_{80}} \times 0·074$ centi-shillings per kw.-hour supplied.
3. Ring mains and transformer stations $K_r = \frac{1}{n_{80}} \times 0·185$ centi-shillings per kw.-hour supplied.
4. Total costs $K = K_c + K_v + K_{sp} + K_r$ centi-shillings per kw.-hour supplied.

The total costs, Item B 4, cover the energy supplied on the low-tension side of the 20,000-volt step-down substations, and can therefore be compared with the costs per kilowatt-hour generated in the existing power stations (see Table IV, Equation 1).

C. *Operating costs of the old plants.*—These are composed of—

1. Capital charges on the real value of the 25 power stations with a total output of 126,000 kw., the amount of which is assessed at 662s. per kilowatt in accordance with Item No. 9, Table II, and
2. The direct operating costs for the three old stations with installed capacity exceeding 10,000 kw. kept in commission. As it was assumed that the economy of these three stations is higher than the general average economy of all London works, I have assumed the cost characteristics follow a curve lying between the average London costs (see Table IV, Item 4) and those of the new power station (Item B 1), deducting capital charges, which are included in the first part of this section.

I have further assumed that, in view of the high proportion of the lighting load, the new power station can deal with the entire supply without assistance during a considerable part of the year, and that the three old power stations need be operated for not more than an average of 8 months in the year.

The utility factors are to be based as regards capital charges on the existing plant of 126,000 kw., and as regards operating costs on the capacity installed in the three old stations of 46,000 kw.

The operating costs of the old plant are then found to be as follows :—

1. Capital charges as hitherto, about 8 per cent on 83,412,000s.—

$$K_z = \frac{1}{n_{126}} \times 0·605 \text{ centi-shillings per kw.-hour supplied.}$$

2. Operating costs for the three old power stations, exclusive of capital charges—

$$K_a = \frac{1}{n_{46}} \times 0·387 + 1·340 \text{ centi-shillings per kw.-hour supplied.}$$

3. Total costs—
$K = K_z + K_a$ centi-shillings per kw.-hour supplied.

The figures obtained from the comparative calculations made on the foregoing basis are combined in Table VI. The results of these calculations may be summarized in the following statement. The plan proposed permits payment of interest and amortization of the old capital in the same manner as hitherto, and leaves a reasonable sum for capital charges on the new capital and a surplus of 5,200,000s. This profit is secured without making any alterations in the existing distribution system. The increase from 135,000,000 kw.-hours to 172,000,000 kw.-hours would meet the natural increase in the consumption during the construction period.

We will now consider the effect of the above scheme on concerns supplying continuous current. According to the statistics of 1910–11, there are 29 companies under this heading with an installed capacity of 116,000 kw. If the largest of these stations with outputs of 10,000 kw. might at first remain in commission (there are three of these works with a total output of 54,000 kw.), the others would be

shut down, and as the ring mains have still an ample reserve, the only alteration would be the installation of 62,000 kw. of converters and transformers, the laying of about 7 additional feeder cables, and the extension of the new power station by 3 generating sets. This alteration could be carried out at a cost of about 310s. per kilowatt installed. After this alteration about 80 per cent of the existing plant will have been combined and transformed into an efficient supply system. The conversion of the remaining concerns with non-standard systems would probably no longer offer great difficulties.

Comparison: Distant and Local Power Stations.

The foregoing calculations were carried out on the assumption that a new power station would be erected in the vicinity of the city supply area. The question that remains to be examined is whether greater advantages could be obtained by erecting the new power station at coal-mines and transmitting the energy to the city by long-distance transmission lines. A general investigation does not appear to indicate promising results. A scheme of this kind is dependent upon a number of factors which vary according to the prevailing conditions. I may mention in this respect that apart from coal freight and the distance of the mines, the price and quality of the coal and the economy of the plant influence the results.

In order to investigate the matter more closely I was obliged to take certain figures as constants and to confine myself to a consideration of the following points:—

Distance of the mines from the city.
Utility factor.
Transmission system (overhead line or cable).

With regard to the constants, I have taken normal values adapted as far as possible to London conditions.

Basis for the comparison of local and distant power stations.

Difference in price of coal delivered free at bunkers	3s. 6d. per ton
Price of coal delivered free at bunkers, distant power station	7s. per ton
Calorific value of the coal	7,000 cal./kg. (12,600 B.Th.U. per lb.)

Economy of power station corresponding to the characteristic for modern plants, Fig. 6.

Cost of power station—	
At the mine	170s. per kw.
Near the city	210s. ,,
Max. output at end of line	80,000 kw.

The last value corresponds to the power-station output in the previous example. Moreover, there will be no essential alterations in the results of the comparison if, in place of 80,000 kw., 2 or 3 times this value is taken, as this merely entails an alteration of the absolute value, while the relative figures which are of importance for the comparison remain approximately the same.

I consider the extra cost of 40s. per kw. for the local power station justified in consequence of the appreciably higher land values, the expensive pile foundations that may be required on the Thames, and higher wages, salaries, etc.

For the long-distance transmission I have selected three-phase current at 50 cycles, with a line pressure of 100,000 volts, both for overhead and cable transmission.

My reason for suggesting such a high working voltage for cable transmission requires some explanation. As the neutrals of the system would be permanently earthed, the pressure between earth and conductors would be 60,000 volts. Single-core lead-covered cables laid direct in the ground with mechanical protection would be employed. Cable manufacture has made sufficient progress for the use of such voltages. Apart from manufacture, the electrical phenomena have also been investigated, and the accompanying difficulties can be overcome. It should also be borne in mind that with such high pressures and the attendant high strain on the insulation, the idea of employing cables cannot be entertained unless the energy to be transmitted is very considerable and the sections of the cable become large in consequence. The recent development towards large power stations and long-distance transmission has therefore advanced conditions in favour of high-tension cables, so that for installations of this kind under certain circumstances as are encountered in large cities, cables appear to be equally satisfactory or even superior to overhead transmission lines.

In preparing comparative calculations I have assumed a smaller average distance between masts than is advisable under ordinary circumstances. In addition I would propose purchasing a strip of land 15 metres wide for each line of masts at an average price of 600s. per ha. (= 2·47 acres).

It is necessary to provide two rows of masts to allow for repairs, whereas with single-phase cables one cable per circuit suffices as a reserve, provided it can be put into commission without interrupting the supply.

Overhead transmission lines cannot be continued as far as the feeding points near the centre of the city, and the main step-down station must therefore be placed on the outskirts of the city unless 100,000-volt cables are used for taking the energy into the city. In the comparative calculations I have taken the first suggestion, and an amount must therefore be included in the estimate for a feeder cable equal to that for the local power station under Item 2 on page 135.

The comparison includes the plant up to the feeding points of the 20,000-volt ring mains (see Fig. 12), as from this point the systems and methods of working are the same for all cases. The distances from the mines are taken as 100 km., 150 km., 200 km., and 250 km. respectively. The costs then work out approximately as follows:—

A. *Local power station* (see page 135).

1. Power station: 83,000 kw.	17,430,000s.
2. Feeder cable: 20,000-volt	5,000,000s.
	22,430,000s.

B. DISTANT POWER STATION WITH OVERHEAD TRANSMISSION.

Installation cost in shillings.

Distance	Power Station	Overhead Transmission	Main Step-down Station	Feeder Cable	Total
100 km.	15,640,000	4,700,000	1,700,000	5,000,000	27,040,000
150 „	15,980,000	7,050,000	1,700,000	5,000,000	29,730,000
200 „	16,150,000	9,400,000	1,700,000	5,000,000	32,250,000
250 „	16,320,000	11,750,000	1,700,000	5,000,000	34,770,000

DISTANT POWER STATION WITH CABLE TRANSMISSION.

Installation cost in shillings.

Distance	Power Station	Cable Transmission	Main Step-down Station	Total
100 km.	14,620,000	10,470,000	1,700,000	26,790,000
150 „	14,960,000	15,915,000	1,700,000	32,575,000
200 „	15,300,000	21,580,000	1,700,000	38,580,000
250 „	15,640,000	27,400,000	1,700,000	44,740,000

The results of the comparison for all the foregoing cases have been tabulated in Figs. 9 and 10. Fig. 9 shows the comparison between a local power station and a distant power station with overhead transmission, and Fig. 10 the same with cable transmission, the values including 10 per cent for the capital charges on the power station and sub-stations, and 8 per cent for the overhead transmission line and cable. These calculations prove that the working costs with cable transmission are higher than with overhead transmission at low utility factors, and that with the utilization of about 50 per cent they are practically equal. The curves further show that under the assumptions made, the local station can be operated more cheaply than the distant station. The operating costs of the former, however, approach those of the distant station, and from a utility factor of 30 per cent upwards exceed them at 100, 150, 200, and 250 km. transmission distances.

CONCLUDING REMARKS.

The comparison has shown that under certain conditions, namely with coal freight at 3s. 6d. per ton and with a normal utility factor, it would be cheaper to operate a power station situated near the city than one at the coal-mines. I do not, however, look upon the difference as sufficient to decide so important a matter as the locality of the power station. There are other considerations of a more general nature that have a considerable bearing on the point at issue.

In this connection it follows from the arguments given that by reducing the operation of the six existing stations more than I have assumed, and using them for peak loads or as a stand-by only, one can obtain a higher economy and reduce the total costs for the power station at the mines.

A variable item in the calculations is coal freight. I have taken 3s. 6d. per ton for freight; it seems unlikely that the freight rates will remain constant for a number of years.

A question which is also of great importance is the possibility of using low-grade fuel at the mine, viz. fuel which it would not be worth while to transport to a power station near the city. One might be able to secure protection against a rise in the price of this fuel by the acquisition of a coal-mine.

The towns and districts surrounding the coal-mine station could conveniently be reached from the same and could thus enjoy the benefits of a cheap and reliable supply.

A much-discussed subject is the extraction of by-products from coal; and it would be of interest to examine under what conditions the processes now in use could be applied in connection with the very large amount of coal that would be required.

These are all considerations that call for a careful scrutiny before deciding on the principles to be followed in connection with electricity supply of large cities.

APPENDIX.

Table I.

General data.

No	Item	Berlin, 1911–12	Chicago, 1911	London, 1910–11
1	Company	Berliner Elektricitäts-werke	Commonwealth Edison Company	Authorities and companies in and around London
2	Population, approx. ...	2,600,000	2,200,000	6,500,000
	Power stations :—			
3	Number	6	6	64
4	Installed capacity ...	137,000 kw.	221,700 kw.	298,400 kw.
5	Average size	23,000 „	37,000 „	4,670 „

Table II.

Capital.

No.	Item	Berlin, 1911–12		Chicago, 1911		London, 1910–11	
6	Assets	160,426,000s.		280,321,000s.		547,060,000s.	
7	Sinking fund, etc.	30,380,000s.		14,148,000s.		111,800,000s.	
8	Real value	130,046,000s.		266,173,000s.		435,260,000s.	
		Cost per kilowatt installed					
			Per Cent		Per Cent		Per Cent
9	Power station	355·93s.	38	477·10s.	40	662·00s.	45
10	Distribution system, including meters	593·69s.	62	723·26s.	60	797·00s.	55
		949·62s.	100	1,200·36s.	100	1,459·00s.	100

TABLE III.

Working results.

No.	Item	Berlin, 1911–12	Chicago, 1911	London, 1910–11
	Capacity—			
12	Total peak load	94,600 kw.	199,300	185,500
13	Peak load per power station	15,800 ,,	31,700	2,900
14	Kw.-hours generated	274,000,000	684,000,000	405,000,000
15	Kw.-hours purchased	—	32,000,000	—
16	Kw.-hours sold	216,300,000	640,000,000	319,243,000
	Comprising—			
17	Lighting	24 per cent	19 per cent	61 per cent
18	Power...	45 ,,	12 ,,	27 ,,
19	Traction	31 ,,	69 ,,	12 ,,
	Factors—			
20	Load factor (kw.-hours generated) ...	33·1 ,,	41 ,,	24·9 ,,
21	Efficiency of transmission system— $\frac{\text{kw.-hours sold}}{\text{kw.-hours generated}}$	0·79	0·894	0·788
22	Reserve factor	1·450	1·11	1·61
23	Utility factor (total)	0·18	0·33	0·122
	Coal—			
24	Price per ton	17·41s.	Approx. 8s.	Approx. 12·8s.
25	Consumption per kw.-hour sold ...	1·38 kg.	,, 1·61 kg.	,, 2·37 kg.
26	Overall efficiency of plant	9·7 per cent	,, 7·6 per cent	,, 5 per cent
	Working costs—			
27	Revenue from kw.-hours sold	34,334,000s.	57,845,000s.	62,400,000s.
28	Expenses	17,636,000s.	28,881,000s.	27,820,000s.
29	Profit absolute	16,698,000s.	28,964,000s.	34,580,000s.
30	Percentage of real value...	12·83	10·87	7·85
	Operating costs per kw.-hour sold—			
31	Selling price	15·856 centi-shillings	9·044 centi-shillings	19·530 centi-shillings
	Expenses—			
32	Fuel...	2·393 ,,	1·146* ,,	3·051 ,,
33	Oil, stores, etc.	0·039 ,,	0·045 ,,	0·262 ,,
34	Wages	0·510 ,,	0·614 ,,	1·047 ,,
35	Repairs, maintenance	0·937 ,,	0·830 ,,	1·482 ,,
36	Rent, taxes, insurance, etc.	0·348 ,,	0·605 ,,	1·482 ,,
37	General expenses...	0·840 ,,	0·836 ,,	1·396 ,,
38	Current purchased	—	0·167 ,,	—
39	Municipal participation	3·067 ,,	0·271 ,,	—
40	Total expenses	8·134 ,,	4·514 ,,	8·720 ,,
41	Profit (gross)...	7·722 ,,	4·530 ,,	10·810 ,,

* The conversion to kw.-hours sold includes the number of kw.-hours purchased; therefore the actual value is approximately 4–5 per cent higher.

Table IV.

Equations for operating costs of existing plants. n = Utility factor.

Portion of Plant	Working Costs including Capital Charges per kw.-hour sold, in Centi-shillings		
	Berlin, 1911–12	Chicago, 1911	London, 1910–11
1. *Power station* (excl. transmission losses)—$K_{centr.}$	$\frac{1}{n} \times 0{\cdot}635 + 1{\cdot}607$	$\frac{1}{n} \times 1{\cdot}071 + 1{\cdot}036$	$\frac{1}{n} \times 1{\cdot}034 + 1{\cdot}946$
2. *Transmission system*—K_{net}	$\frac{1}{n} \times 0{\cdot}821 + 0{\cdot}033$	$\frac{1}{n} \times 1{\cdot}114 + 0{\cdot}057$	$\frac{1}{n} \times 1{\cdot}111 + 0{\cdot}026$
3. *Transmission losses*—			
(*a*) $V_{kw.}$ = kw.-hours	$\frac{1}{n} \times 0{\cdot}028 + 0{\cdot}111$	$\frac{1}{n} \times 0{\cdot}017 + 0{\cdot}068$	$\frac{1}{n} \times 0{\cdot}022 + 0{\cdot}088$
(*b*) Cost	$V_{kw.} \times K_{centr.}$	$V_{kw.} \times K_{centr.}$	$V_{kw.} \times K_{centr.}$

Table V.

Assumptions made for division of the working costs.

Position	1	2	3	4	5	6	7	8	9
	Division of Working Costs per Kw.-hour sold								
	Working costs . $\frac{\text{Power station (incl. transmission losses)}}{\text{Network costs}}$							Dependent upon Utility Factor	
	Installation costs . $\frac{\text{Power station}}{\text{Network}}$				Working costs . $\frac{\text{Power station}}{\text{Network}}$				
	See Items 9, 10 Table II			Without	With Reference to Installation Costs				
	Berlin	Chicago	London		Berlin	Chicago	London	Dependent	Independent
Fuel	0·61	0·67	0·82	∞	∞	∞	∞	$\frac{1}{2n} \times 24$	$100 - \frac{1}{2n} \times 24$
Oil, stores, etc.	0·61	0·67	0·82	4	2·45	2·67	3·27	70	30
Wages	0·61	0·67	0·82	4	2·45	2·67	3·27	70	30
Repairs	0·61	0·67	0·82	4	2·45	2·67	3·27	80	20
Rent, taxes, etc.	0·61	0·67	0·82	1·5	0·92	1·00	1·23	90	10
General expenses... ...	0·61	0·67	0·82	4	2·45	2·67	3·27	90	10
Capital charges	0·61	0·67	0·82	1	0·61	0·67	0·82	100	0
Transmission losses ...	0·61	0·67	0·82	—	—	—	—	20	80

TABLE VI.

Comparative summary of the working results before and after reconstruction, substituting one large power station for 25 existing power stations, and partially utilizing the three largest of the aforesaid power stations.

No.	Item	Before Reconstruction	After Reconstruction
1	Available capacity at sub-stations of ring mains or at the outgoing feeders of the old power stations	126,000 kw.	126,000 kw.
2	No. of power stations	25	4
3	Installed output—		
	New power station	—	83,000 ,,
	Old power stations	—	46,000 ,,
4	Feeder cable losses per kw.-hour sold	—	0·041 kw.-hour
5	Total efficiency of transmission system— $\frac{\text{kw.-hours sold}}{\text{kw.-hours generated}}$	0·788	0·788
6	Total load factor of power stations	24·9 per cent	24·9 per cent
7	Total reserve factor	1·61	1·25
8	Total utility factor $= n_{126}$	0·122	0·156
9	Energy sold per year per kilowatt installed...	1,069 kw.-hours	1,370 kw.-hours
	This energy supplied as follows—		
10	From the old power stations, eight-months service, $n_{46} = 0·156$	—	333 ,,
11	From the new power station	—	1,037 ,,
	Utility factor—		
12	Old power station, n_{46}	—	0·156
13	Large power station, n_{80}	—	0·186
	Working costs per kw.-hour supplied on entering the low-tension network—		
14	New power station (incl. 10 per cent capital charges) ...	—	4·878 centi-shillings
15	Old power stations (excl. capital charges)...	—	3·820 ,,
16	Capital charges on the 25 old power stations (8 per cent as hitherto)	—	3·874 ,,
17	Average price per kw.-hour supplied...	9·440 centi-shillings	8·510 ,,
	Working costs for the low-tension network per kw.-hour sold—		
18	Losses per kw.-hour sold	0·268 kw.-hour	0·229 kw.-hour
19	Cost of losses	2·480 centi-shillings	1·940 centi-shillings
20	Working costs (incl. capital charges, 8 per cent as hitherto)	7·610 ,,	5·966 ,,
21	Total costs (incl. capital charges) per kw.-hour sold ...	19·530 ,,	16·416 ,,
22	Capital	183,830,000s.	218,010,000s.
23	Energy sold per annum, kw.-hours	135,000,000	172,000,000
24	Annual revenue	26,400,000s.	33,600,000s.
25	,, expenses	26,400,000s.	28,400,000s.
26	Available surplus...		5,200,000s.

DISCUSSION BEFORE THE INSTITUTION ON 4TH DECEMBER, 1913.

Snell. Mr. J. F. C. SNELL: I propose only to deal with a few of what appear to me to be the most salient points in Dr. Klingenberg's address, and not to go into such details as utility factor or his other useful equations. I feel a very full sense of responsibility in speaking upon a question of this sort because it is very obvious that Dr. Klingenberg's address is directed particularly to the supply of electricity in London. As that is a matter with which I have had a good deal to do during the last 6 or 7 years I feel, as I say, a full sense of responsibility, a sense of responsibility to the London County Council, and also to those who are at present advising the Council, in that I do not wish to overstep the limits of proper discussion while this matter is still *sub judice*. I think we shall agree with Dr. Klingenberg where he says that if we were dealing afresh with the electricity supply of any great city, London or elsewhere, any engineer to-day would suggest one or more large three-phase stations generating at perhaps a moderate pressure, stepping up to a higher pressure for transmission, and stepping down at strategic points to three-wire or four-wire low-tension distribution for general supply, *i.e.* lighting and power, and of course converting for traction supply. Nobody will to-day disagree with such a statement as that, but in London we have very peculiar difficulties. In the first place the County Council have the power to purchase the present companies in the year 1931 on the terms of the 1888 Act, which up to the present are undefined; by that I mean that they have not been fought out in the way that Section 43 of the 1870 Tramways Act has been fought out, and nobody knows what the exact terms of purchase will be. Under those conditions it is obvious that the companies must have difficulty in raising money for extensions, and this difficulty will increase the nearer we approach to 1931, so long as the present conditions of purchase remain unaltered.

I should like to refer to one or two axioms which I think most power-station engineers will accept. One is this, and it has been impressed upon me very clearly in dealing with a number of metropolitan undertakings during the last 4 or 5 years, if we consider a station of moderate size the cost of extending that station to-day is not very high, and the cost of producing energy from the new plant is really very small indeed, and it is a very difficult matter for a bulk supply, no matter how favourably placed, to deliver electrical energy within certain limits at a cheaper rate than it could be generated from that extended plant. It must be remembered that I am now referring solely to the additional plant. In the second place, everybody will agree that if there were virgin ground where there was no local supply of electricity and a proper bulk supply was available, no engineer would dream of erecting a small local station instead of purchasing energy in bulk and distributing it accordingly. But in dealing with the supply of energy in bulk, as I think I pointed out in 1904, we must bear in mind that the reduced cost of energy due to the larger plant and probable higher load factor, may be neutralized by the cost of the transmission mains and by the losses in conversion from alternating to continuous current. There are those three points therefore which have really to be kept in mind.

We have heard a good deal about the backwardness of electricity supply in England. Mr. Mordey dealt with that Mr. Snell. in his Presidential Address,* and Dr. Klingenberg has referred at length to the supply in the city of Chicago. Now let us see what is actually the position there. The capital invested is roughly £15¼ millions, or £69 per kilowatt. The average cost throughout Greater London is £80 per kilowatt, but in Chicago the greater proportion of the supply is given for traction; thus of the total number of units sold, namely about 712 millions, no less than 484 million units are sold for traction, or, as called in America, transportation systems. Then 480 million units are sold at an average cost of 0·405d. at a load factor of 50 per cent. If I deduct from the total the number of units sold for traction, I find that there is a remainder of 229 million units for lighting and power, from which a revenue of approximately £2¼ millions was obtained, the average price being 2·34d. Dr. Klingenberg actually mentioned that figure, or practically that figure. The average price in London is 2¼d.; so that if we compare the average cost of electric light and power in Chicago, the "Electrical City" as it is called, with the cost of lighting and power in London, there is not much difference. Let me be fair; I appreciate that the conditions of living are different in America from what they are in London; the cost of living is higher, but I doubt if there is any serious difference in the cost of producing electrical energy. Omitting the traction supply, the number of units sold per head of population in Chicago was 105 in the year 1912, compared with 70 in Greater London, again excluding traction. In the district of Marylebone, which has the largest output *per capita* at the present moment, the consumption of electrical energy is 100 units *per capita*; so that there is not a great deal of difference between Marylebone and Chicago in regard to the sale of electrical energy for lighting and power. Indeed, in Marylebone I understand that the greater part of the supply is for lighting and heating, together with a certain amount for cooking. If, again, I take one of the large power companies in New York, I find that with plant installed of 217,000 kw. capacity the capital expended is £113. The average price per unit is 3⅝d.—that figure, however, includes the supply of a certain number of free lamps—and the number of units *per capita* is 119. Similarly in Boston the number of units is 110 *per capita*. So that there is not a great deal of difference, when we compare like with like, between the sales of electrical energy in Chicago, Boston, New York, or London. The whole point lies, of course, in the fact that the transportation systems in London are not developed to their full extent, and therein, I think, lies to a large extent the key to the situation. What is the position in London? The output at the present moment is 460 million units, the number of kilowatts installed is 320,000, and the actual cost of land, buildings, and plant is roughly £41 per kilowatt—that is approximately one-half of the total capital invested in the whole of the undertakings. But here is an important point: the total of all the maximum demands in London last year was 203,000 kw., and the capacity of the plant installed was, as I said, 320,000 kw., leaving no less than 117,000 kw. in reserve,

* *Journal I.E.E.*, vol. 42, p. 10, 1909.

Mr. Snell

or practically 36 per cent. That of course is one of the direct results, as Dr. Klingenberg pointed out, of having the plant distributed over a large number of comparatively small stations. The utility factor was low. The actual capital investment in the 64 stations—that is investment in land, buildings, and plant—is approximately £13¼ millions. Without going into details, I may state that the cost of replacing that plant by two bulk stations at a moderate distance from London, with the necessary transmission mains and converting or transforming apparatus which would be required in the existing stations, would be approximately £6,000,000, so that there would be an actual saving in capital of £7,000,000 if we had not got the 64 existing stations and could begin anew with two bulk stations. What would be the saving in the working? I have calculated this out with care, and find that the cost would be somewhere in the neighbourhood of £1,000,000 per annum, that is 0·58d. per unit delivered to the consumers, or a reduction on the present average charges in London of 26 per cent. Of course that would be a splendid thing if we could only do it; but, unfortunately, that is not the position. We cannot ignore the existing stations, so what we have to consider, as it seems to me, is: What is the best compromise that can be arranged? I know I shall be criticized; but my own personal belief is that the psychological moment (which might have occurred 8 or 9 years ago) for a bulk supply of electricity to the whole of the traction undertakings of London has passed away. There are some suburban lines, of course, still unelectrified, and no doubt if proper terms were offered them they might, as in the case of the London, Brighton, and South Coast Railway, purchase their energy in bulk; but some of the great railways, those that have the best suburban services, like the London and South-Western Railway, the London and North-Western Railway, the Great Northern Railway, and the Great Western Railway, already have power stations, or soon will have power stations, of their own. They have started to build them. I think that has put back, at any rate for a great many years, the chances of any great amalgamated supply selling energy to those suburban lines. That makes a great difference to the whole situation, as it seems to me. If that may be granted, we, I think, come to the point: What can we do to wipe out some of this large number of small stations and replace them by stations which will supply energy at a cheaper rate? I myself believe, from a fairly intimate knowledge of all those stations, that there are some 8 of them which should be retained. It would pay, moreover, to extend these stations because of their geographical positions and certain facilities which they enjoy. I believe, too, that it would be possible to use those 8 power stations not only to supply the areas which they are permitted by Parliament to supply, but also to go beyond those areas. Let me call those the first-class stations. Secondly, there are about 10 stations it would pay to extend to a limited degree—limited, I mean, either by the facilities which they can obtain for condensing purposes, or the limitations of a circumscribed site or of coaling. The other stations, which number about 36, will, in my opinion, be gradually superseded. It will not come at once; it cannot come at once, except in a few places, because of the money which has been invested in those power stations.

Mixed up with this problem of the present is the problem of the future. Let me leave aside for the moment, for the reasons which I have stated briefly, the question of a big transportation load; and let us consider what is likely to be the growth during, say, the next 10 years. Of course it will be said that it is a very hazardous guess—I admit that it is—but let us assume, and it is somewhat borne out by statistics for the last 2 or 3 years, that in the next 10 years there may be an increase in capacity of 150,000 kw. What will be done with it? All engineers will agree that it would be unwise that 150,000 kw. should be spread in small units over 64 stations. I do not suppose that will be done. I think, therefore, if facilities could be given at once for the starting of a well-placed bulk station, that plant can be installed in that bulk station to meet this gradual growth. Having got that station started, and possibly a little later a second station, we should be in a position gradually to shut down the 36 small stations which I mentioned. Let me summarize for a moment at this point. I say that there are existing capital commitments which cannot be overlooked, and that only a gradual replacement of the existing plant can take place. I believe the best solution at the present moment, and I say it unhesitatingly, is that the generation of energy in London should be in the hands of one authority, and that this authority should supply energy wholesale to existing authorized distributors, and that these authorized distributors should continue to exist as distributors, and manage the business in their own local areas—not only up to 1931, but afterwards.

Dr. Klingenberg next goes on to discuss the relative merits of stations placed close to London and stations situated, as he terms it, at the pit's mouth. The nearest coalfields we have are the Kent, partially developed, 50 miles in a straight line from London, and the Nottingham and Western coalfields, about 100 miles from London. He takes as his comparative figures £10·5 per kilowatt for the stations near London, and £8·5 per kilowatt for the stations situated at a distance. If he knew England and those districts round the coal-pits fairly well, I think he would naturally ask himself what is he going to do, at any rate in the Midland coalfields, for a supply of condensing water, because it seems to me for high turbine efficiencies a good supply of circulating water is as necessary as a cheap supply of coal. First of all, I would assert that a very marked economy would have to be shown to Parliament and the other authorities interested before they would be content for the supply of London to be dependent upon a very high-pressure supply obtained at so great a distance from London, with the undoubted—I do not wish to magnify them—extra risks which such a system must necessarily entail. I think everybody must agree that the further we go afield and the higher the pressure the greater must be the risk. Anyway, let me put it fairly at that. Then when in America and other places they take energy from a very distant station they install batteries to a great extent in the cities. I do not think Dr. Klingenberg has taken batteries into consideration. They have a fairly high initial cost, and a moderate cost for maintenance. But looking at some of his estimates—necessarily I have had to do it rather quickly—I must confess that I think some of his figures are considerably open to criticism. For instance, he talks about the cost of transmission lines, two lines being taken over a strip of land 15 metres wide for a distance of 62 kilometres, or 100, or

Mr. Snell. whatever it is, and says that the price is 600s. per hectare. Now a hectare is $2\frac{1}{2}$ acres. Does he think in England he will get land at £12 an acre ? It ought certainly to be multiplied by at least 7 or 10. I have increased the figure of £485,000 for the two lines to £600,000. It is not a very large alteration, but the total cost of the distant station with 92,000 kw. installed, that is to say capable of delivering 80,000 kw., would be approximately £1,500,000, or £18·3 per kilowatt installed. The local station, taking Dr. Klingenberg's own figures, would be £871,000, or £11 per effective kilowatt. What saving do we get ? He assumes a saving in carriage of 3s. 6d. per ton of coal. If the station had an annual load factor of 35 per cent, which I think is a reasonable figure to take, the coal consumption would be about 250,000 tons per annum, and the annual saving therefore would be about £44,000. That is, I think, the *maximum* saving which would be obtained as between stations placed at a distance of 50 or 100 miles from London, and a station at the outskirts of London. There might be some saving in wages, but it would be very slight. There might be some saving in rating, but I think that the assessment on the transmission lines would neutralize the reduction in the assessment on the power station. I cannot see any other saving. I will confine myself to this. There would be a saving in coal of £44,000 a year ; but Dr. Klingenberg has had to spend practically another £500,000 and has to pay the capital charges upon that. Taking it on, I think, a very fair basis, taking, for instance, the life of transmission towers at 40 years, I estimate that the capital charges alone would absorb £12,000 per annum ; *i.e.* there is still a saving of £32,000. Then there is the cost of patrolling and maintaining the lines, painting the towers, and certain repairs ; it may be said this is not a very big figure, but still it all costs money, and I think when we come to take a line in England of 100 or 50 miles it will be found that that item accounts for a few thousand pounds a year. Putting it briefly, I come to this conclusion, that taking a station 50 miles away we might possibly obtain a saving of £20,000 per annum. What would it mean ? The station would be capable of generating 200 million units per annum—it probably would not do so much—and the revenue would be approximately—I do not mean to say the cost of energy sold to the consumer, but the revenue as a power station—£275,000 a year. We thus get a saving on paper of £20,000 a year on a revenue of £275,000, whilst taking the risks of a station supplying energy at very high pressure over a distance of 50 or 100 miles. I confess I do not believe that would commend itself to the authorities. I do not know that it will commend itself as an engineering adventure to engineers. Finally, I may say this, and I am not speaking at random ; four or five years ago Mr. Felt, Mr. Rider, myself, and others, had to go with great care, and with as much exactitude as we could muster, into the relative cost of a station situated 40 or 50 miles away from London and a station situated only 10 miles away, and on estimates carefully confirmed we came to the deliberate conclusion that the home station, a station within 10 or 15 miles of London, was the cheaper proposition and the better engineering proposition.

In conclusion let me just say this. What we ought to be concerned about as engineers and as an Institution is this. We do not want to see the development of electricity in London delayed by inept legislation or by the play of political parties, or by its being made the sport of financial groups. What we do want to see is that there is freedom given for the proper and careful development of the supply in this great city. Mr. Insull is reported in the *Times* only a day or two ago, in his speech to the Investment Bankers' Association of America, to have said that the greatest item of expense is not the cost of coal or of labour, but of money, and I think most of us will agree that that is true. Therefore I say that what is wanted is an accelerated development, a supply consistent with a proper regard for existing conditions and future growth, and I believe that the best solution is the gathering together of all the generating stations in Greater London into the hands of one constituted authority now and not 18 years hence ; and that that constituted authority should supply energy wholesale to the existing distributors, leaving the existing distributors, whether company or municipal, the enjoyment of their present areas, the right to distribute energy, and the right to manage their own local business.

Dr. Ferranti. Dr. S. Z. DE FERRANTI : The greatest compliment that we could show Dr. Klingenberg would be, rather than our applause, a full, complete, and satisfactory discussion on his address ; but I should like to explain for those who do not know it, lest this discussion might be considered representative of English electrical engineers, that many if not most of the engineers whom we should like best to have heard are precluded from speaking upon this subject by the position of electrical affairs in London at the present moment. Now from my point of view, if I were coming to London and looking at this electrical supply for the first time, I am afraid I should be led to think it was about the maddest arrangement that it was possible to conceive in the way of electricity supply, and no doubt many engineers and many business men in other countries think what a wonderful people we must be to have conceived such a terrible state of affairs for our capital city. Well, now, the trouble is not electrical, and it is not engineering ; the problem originated long ago in the desire to make a huge experiment, and in my opinion resulted unsatisfactorily from the preponderance of the politician over the engineer and the business man. The primary object was to benefit the public, and usually when legislation tries particularly hard to benefit the public, the public is nowhere except in the way of paying. Now gasworks were very successful in the early days in this country, and this success has continued. Years ago when electricity was just starting on its business career for what I should call the heavy side, that is to say apart from telegraphy, there was a great feeling that everything of the nature of public supply should be carried on in the interests of the community. In other words it was desired to make municipal trading of it, and electricity being the newest thing, the most promising thing, and with the least strength to support and defend itself, was taken hold of by the politicians in the name of the public, and London's present system of electricity supply has been the result. There was no consideration of what were the best positions for stations and the best areas of supply, but the only guiding idea was that each parish or local authority should have its own small electricity supply all to itself. That is how the present state of affairs originated. Where the municipality did not get this power and a company came in, the trouble was further

Dr. Ferranti. aggravated by the fact of there being two companies, not who might work sensibly together, but who were forced to compete and offer two kinds of electricity supply, namely, continuous and alternating current. Thus Dr. Klingenberg and engineers in other parts of the world must not imagine that London is part of an electrical design; they must know that it is part of a bad system in the first instance, but not of our making.

I notice that Dr. Klingenberg has considered in his address the alternating-current stations supplying at 50 periods, and as this presumably is the easiest part of the supply to combine under one scheme, he has based his calculations on a station to supply these districts. This appears to me to be an ordinary business proceeding with a view to getting a quick return, that is to say, upon the narrowest case to show a justification for a unification of system and supply. But I think that the necessary change will hardly be brought about on an argument of this kind. He undoubtedly shows a saving, although this has been questioned by Mr. Snell. He has gone into it very fully, and I think there is little doubt as to the saving and the desirability; but I do not think any such argument or any such proposition would be sufficient to convert us from the present state of affairs and bring about something more desirable. There must be some great advantage to the public if any great change is to be made. In my opinion that advantage to the public is so changing the whole idea that the public can be supplied at a price which will make electricity practically universal and lead to its adoption for every conceivable purpose in this great city. Of course this involves a number of things. We have heard about the serious capital expenditure which has already been incurred, and Mr. Snell specially emphasized that fact; that is to say, we are so deeply committed that it is considered almost impossible to make a change, and if things only go on a little longer that change never can take place. But I have long felt that when electricity supply is so altered that electrical energy can be supplied at what I consider more nearly its correct price, it will develop on such a scale that the past capital expenditure will sink into insignificance. That, I believe, will be the true justification of the changes which must be made at some time later on.

Now Dr. Klingenberg has purposely stated that he deals with lighting, power, and traction, and for the moment leaves out of consideration heating and cooking. There again is the business instinct of the argument of dealing with what exists at the moment. But in this matter of electricity supply I think we have had almost too much of the present knowledge in relation to what may come in the future. When we look back a little way we see how very rapidly things have advanced and how what seemed impossible yesterday is being done to-day. It is simply repeating what I have already said in another form. My view as to the demand is this, wherever there is fuel combustion at present, there is the demand; and it is for electrical engineers to devise such means and improvements in the processes of conversion as will secure for us that demand. Fuel combustion within the cities will then be replaced by energy supplied electrically from without those cities.

Now there is one point in which I agree with Mr. Snell; namely, about stations distant from the area of supply. I have often seen the remark attributed to me, or as part of what I have advocated, that power stations should be placed on the coalfields and the electrical energy transmitted to the great centres of demand. I do think, however, that the governing factor in the placing of the generating station, that is to say the station where the heat energy is converted into electricity, is the water supply. The water supply is enormously important to-day; and I see no method, so long as the converting process is thermal—that is to say, one in which there is a rise and a reduction of temperature—where the cooling water will not play a most important part. I have felt that the large generating stations necessary for electricity supply must be on the seaboard or on rivers of sufficient size to provide an ample supply of cooling water. As far as we are concerned in this country, I do not think that the coalfields, generally speaking, offer this facility. However, Dr. Klingenberg has shown that there is not much difference in the way of economy between the station near to the great centre of demand, and the distant station on the coalfields.

In considering the supply of electricity to the public, the problem, to my mind, is not how much more cheaply can we provide the existing supply, but for a little more revenue how many times can we increase the number of kilowatt-hours sold to the customer? Electrical engineers want to get a bigger revenue out of every customer, not in order to obtain a better price for the commodity they supply, but because they want to replace with their commodity what the public is at present spending money on in other directions; in other words, we wish to do everything electrically. Now the great means of reducing the cost of supply is this. I should say there are two great means; but the principal one is extending the time over which the article is sold. We all know the trouble of load factor. The railways are troubled with it in taking the people into the city in the morning and out of it in the evening; the restaurants are troubled with it by everybody wanting to eat at one particular meal-hour, and so on. But I think that it affects the electrical business more than any other. Electrical engineers have got to supply the public with what it wants, and to supply it in the way we want. The public want electricity when they need it, and we want to supply it throughout the 24 hours. We do not see our way, however, to supply light in that way. Light to-day requires a comparatively trifling amount of energy, and when we get that "cold light" about which people are talking, even more than now will the amount of energy required for lighting be small, and so the peak resulting from it will not be serious. The other great demand, of course, in cities is traction. Fortunately it is spread over many hours, and the load factor of traction is very good. The power load in big cities is also satisfactory, broadly speaking. The least satisfactory part is what is going to be a very big demand in the future, at any rate for a city like London, where the temperature is comparatively equable. I refer to heating and cooking. It is the business of electrical engineers to find out means by which heat that is generated electrically can be efficiently stored so that the public can have it when they want it, and yet we supply it when we want to, namely over the whole 24 hours.

Now there is another point. In laying out any area we must look, although it is perhaps far in the future, to what

Dr. Ferranti.

would probably be the demand if the whole energy consumption of the district were supplied electrically. I think that is a point of great importance. It need not interfere with the design or the execution of the present schemes, but it must be one of the matters for consideration, and it must be taken into full account before coming back to the scheme that it is decided to adopt for the moment. There is another thing I should like to say: London is the greatest aggregation of human beings in the world, and yet I do not think London is big enough to be considered alone. It is doubtful how far its stations can be really within its own area. Its fuel supply will certainly not come from within its own area. The industries and the demands of its population do not necessarily provide all the demands which should be supplied from any great electrical system. For these reasons I think that even London, although it is the most remarkable case in the world, is really not big enough to be considered alone. Of course this would apply much more to other cities in proportion as they are smaller, and I should like to emphasize this point. The areas of supply and their relation with adjoining areas of supply should be arranged upon an engineering basis and not upon a local authority or a city basis which has grown up for quite different reasons. Electricity supply, in my opinion, is a matter of national economy; a great deal depends upon it, and I think that properly carried out to its logical issue it is the greatest labour-saver with which we have any prospect of dealing. It can considerably affect the economy with which the country provides itself with its wants; and therefore the whole problem must be looked upon very broadly, bearing in mind its immense importance to the community.

Mr. Seabrook.

Mr. A. H. Seabrook: I am afraid that I am not in a position to discuss this address in the detailed manner in which Mr. Snell has dealt with it. There are one or two broader questions, however, that have not been referred to, although Dr. Ferranti has covered a great deal of that ground. Early in his address Dr. Klingenberg refers to the control of such important public services as the electricity supply of big cities; I should like to draw the attention of those who are likely to control such undertakings in the future and of those who control them at present, to the kind of partnership arrangement which exists in both those cases that Dr. Klingenberg has dealt with, namely, Chicago and Berlin. Mr. Insull seems to have driven the better bargain by having to hand over only 3 per cent of his company's revenue, whereas Dr. Klingenberg has to give up 10 per cent to the Berlin municipality. Electrical engineers claim to be apostles of economy, and in view of the achievements of the industry I think they are quite entitled to that claim. There is one thing which we really ought to go into very seriously, and which is referred to by Dr. Klingenberg; that is the future method of raising steam, whether we are to continue to destroy what one may call the national asset, coal, by burning it on boiler grates as we do to-day, or whether we should not immediately look into the question of gasifying coal, thereby recovering its valuable by-products and using the gas for raising steam in boilers (a gas turbine is not available at the present time, but I think it is unwise to say that a gas turbine is impossible). One or two installations have been recently completed: the latest is that of the Accrington Corporation, but this has not been in operation long enough for reliable figures to be published, although the results so far obtained seem to be very satisfactory. I am glad to see that Dr. Klingenberg deals at considerable length with the question of the generation of electrical energy at the pit's mouth. I think it is quite reasonable to say that electrical energy may not be economically generated in the Midland coalfields on account of the lack of condensing water, but Kent coal will within five years be an obtainable commodity. That coal is particularly friable, and I think it is not suitable for transport; but the Kent coalfield is surely near enough to the sea for all the condensing facilities required for power stations. I believe Dr. Klingenberg has had actual experience of supplying energy in this way, and I hope he will say something about it in his reply, because I believe he is gasifying coal now outside Berlin, generating electricity on the lines indicated and transmitting it to Berlin. We may not be able to go all the way in the case of London's electricity supply, but even if generation in Kent is not feasible at the present time it should not be overlooked. One or two large generating stations on the Thames during the next few years could eventually be supplemented by the generation of electricity at the pit's mouth.

Mr. Tapper.

Mr. W. C. P. Tapper: Dr. Klingenberg's address has come at an opportune moment, when the minds of all interested in the future supply of electrical energy to London are more or less perturbed, some by fears and apprehensions, others by hopes and expectations, and others again by a sincere desire to bring the electricity supply of London up to date, and to put it on a really sound basis.

History.—The author's remarks on the electrical history of the three selected cities are very interesting. Up to a certain point Chicago and London have proceeded on somewhat similar lines, and I have no doubt if the whole supply of London could be put under a single controlling body that London would witness a similar rapid development to that which has taken place in Chicago. I am sorry that the author has not been able to obtain any figures for London later than 1910–11. These figures, owing to the very rapid increase in output during the last two years, are now quite out of date, and to that extent reduce the value of any comparisons based on such figures.

Factors determining the cost to consumers.—I entirely agree with the author on the very great importance of keeping down the capital cost of plant, etc., and also that within certain limits large generating units will effect this object. (In passing I may say that in this country there are undertakings of which the capital charges amount to more than the total of all the other costs.) The author advocates a single large station. Considerations of safety and the cost of high-tension transmissions would make it unwise to concentrate the whole supply for a city like London in a single generating station. The size of the unit would therefore be determined from the number of stations decided upon, and the amount of spare plant required in each. He also advocates uniform alternating-current distribution, presumably three-phase. On this point I entirely disagree with him. In the first place, in London it would cost several million pounds to convert the distribution networks and the consumers' wiring and apparatus to such a system; and any advantage gained

would be more than counterbalanced by the heavy capital charges on the cost of such alteration. Again, with alternating-current distribution the supply authority has little or no control of the power factor. This will involve from 15 to 20 per cent larger generating plant, transmission cables, converting plant and distribution cables. This increased capital cost would form a very serious set-off to any savings in other directions. If the distribution is by continuous current, effective control of the power factor on the high-tension system is obtained. Another important point is that power consumers are more easily obtained and retained on a continuous-current supply than on an alternating-current supply. Under the heading of capital charges the author refers to the question of the allocation of profits. I am in entire agreement with him on that point. The municipal authorities should not participate in the profits, but they should secure that a certain proportion of the profits should be given to the consumers in the shape of reduced charges.

Utilization.—I am not quite clear as to whether the author attaches any importance to the distinction between the terms "utilization factor" and "utility factor." The first appears to be the annual load factor with reference to the maximum safe load on the plant, and the second with reference to the maximum observed or peak load on the plant. In determining the charges for new business the first (*i.e* safe plant capacity) may be taken into account, but in ascertaining actual costs from time to time the peak load must of course be used. The author does not appear to have allowed for the effect of diversity factor in determining the possible selling price. I am sorry that Dr. Klingenberg has chosen the shilling as his unit of money. We are so used to thinking in £'s per kilowatt and pence per unit, that shillings and centi-shillings considerably increase the difficulty of following the author's figures. I also regret that the author has introduced another method of arriving at the cost of giving a supply to different classes of consumers with varying load factors. The suggestion of dividing what are called the standing charges by a number representing kw.-hours must involve misleading results. Nothing can be simpler than the principle laid down by Dr. Hopkinson, and elaborated by Mr. Arthur Wright, of dividing the total cost into standing and running costs, and stating the first in terms of so much per kilowatt per annum, and the second in so much per kw.-hour. The author states that he has shown it is possible to generate at the same prices for lighting, power, and traction, and then states that, as prices can be kept up for lighting, traction can be reduced (presumably down to or below cost). This statement contains, in my opinion, two serious fallacies. First it is an unsound principle to make a surplus on one class of supply and use that surplus to sell at or below cost to other classes. Again, the author ignores the diversity factor, as I have previously pointed out. If this factor is properly allowed for, it will be found that, contrary to the author's statement, lighting, power, and traction do not cost the same, the cost of each class of supply bearing a close relationship to the diversity factor of that class. The lower the diversity factor the greater the cost.

One suggestion put forward by the author opens up great possibilities. I refer to the making of gas, burning the same under steam boilers and selling the by-products. The gas companies are experts in the making of gas. Why should not the gas companies and the electricity supply industry co-operate, the gas companies supplying the gas at a low rate to the electricity supply undertakings, and the latter burning it under boilers and generating cheap electricity thereby? It may be said that it would be more economical to burn the gas in a gas engine, but we must remember that a 30,000-kw. gas engine or gas turbine has yet to be built. Can the author give any information as to the use of single-core lead-covered cables for extra-high-tension alternating-current work, and as to the sheath losses in such cables? With regard to overhead transmission, I think it would be quite impracticable to supply a city of the size of London by overhead lines. If the Post Office find it necessary to put their trunk lines underground in the country districts to prevent interruption, it is obvious that the power conductors supplying London would also have to go underground. This being so, it is probably cheaper and certainly safer to bring coal to London. Mr. Tapper.

Mr. Sayers. Mr. W. B. SAYERS (*communicated*): I wish to refer to three significant sentences: two of these occur in the address, and the third was uttered in substance by Dr. Ferranti in the discussion. Dr. Klingenberg remarks: "What is necessary is to alter the nature of the consumption." About two years ago I contributed an article to the *Glasgow Herald* on the "Cost of Electricity Supply." In that article I endeavoured to bring home to the public—especially those responsible for the conduct of industrial concerns—how a recognition of the facts which govern the cost of electrical energy, and conformity wherever possible with the principle of taking a supply for any purpose at the time of day or night when the demand on the station is a minimum, might secure to them special low terms, and would in any case react to their ultimate advantage by enabling the suppliers to reduce the price to all consumers. Switches operated from the supply station can of course be employed to secure that the conditions agreed upon are carried out—at least in some cases. The problem is to get those of the public who can determine or influence the matter to appreciate its importance from the point of view of the public welfare, efficiency, and economy, and then have the public spirit to act although the immediate visible gain or advantage may be small.

The second sentence by Dr. Klingenberg and the remark by Dr. Ferranti I will deal with together, as the latter sentence emphasizes the objection to the former. The author in his concluding remarks says: "One might be able to secure protection against a rise in the price of this fuel by the acquisition of a coal-mine," and Dr. Ferranti said in effect, "The aim of electricity supply concerns must be to replace combustion wherever found within the city." The ideal expressed by Dr. Ferranti is what we look forward to ultimately, but it gives an undoubted and emphatic negative to the suggestion often made before and now discussed by Dr. Klingenberg of a large bulk-supply station or stations at the pit's mouth. After all the time, labour, money, and experience that have contributed to make electricity supply dependable and reliable as it is to-day (which reliability is a *sine qua non* to its continuance and progress), it is preposterous to propose to make the City of London dependent for light, power, traction, heating, cooking, and every other purpose where energy is required, on a single coal-mine, or even group of mines. Suppose the coal-mines were purchasable at a reasonable price. Is there any coal-mine

Mr. Sayers. which is immune from possible failure through accidents such as fire, water, explosion, faults in the seams? Or against strikes or disputes among miners and workmen? Compared with this main question of immunity from risk of failure or interruption of supply even the matter of condensing water is trivial. It requires but a thought from this point of view to arrive at the conclusion that not only must any bulk-supply station on which London may be largely dependent for its supply of electrical energy be located where there is abundant water as well as fuel supply, but without doubt it must be possible to maintain the supply of fuel of any description—coal, oil, or other combustible—both by land and by sea transport, and in case of emergency to ensure the security of such supply by means of the national resources.

Dr. Klingenberg. Dr. G. KLINGENBERG (*in reply*): In replying to the questions that have been asked, I will first refer to the points raised by Mr. Tapper. I am not advocating for large cities only a single power station: the reason why I have based my calculations for the numerical example in the case of London on one station is because, under the assumptions made, the capacity of the station amounted to only 80,000 kw. at the start and 140,000 kw. after the first extension. This I consider in no way excessive, especially if the sectionalizing of the station is provided for, either by reactance or through the feeding system itself.

With regard to the question of continuous current or alternating current for distribution, I entirely disagree with Mr. Tapper. I consider alternating current in no way inferior to continuous current as far as the convenience of the consumers is concerned, and I would mention only the transformation of an alternating voltage and the simplicity of polyphase motors. As regards cost, there can be no doubt that a pure alternating-current system comes out cheaper in a good many respects. It appears to me that Mr. Tapper is over-estimating the effect of the power factor, which, assuming for instance the present load conditions in London with 60 per cent of lighting, promises to prove quite satisfactory, and which could be regulated to almost any desired value if the percentage of traction be increased, as certainly will be the case in future. I am not proposing, in considering the possible improvements of present systems, to change the existing continuous-current distribution at once into alternating-current distribution. From the example which I have given in my address it will be seen that I am advocating a postponement of any alterations to the existing distributing system because the improvement achieved as regards the total selling price compares very unfavourably with the capital involved in such alterations (see Table IV, Equations 2 and 3). I also emphasized, as the principle for proceeding with alterations, the allocation of the various costs by separation and studying their dependence on the utility, thus determining the gradient of improvement (as regards the cost of energy) on the various parts with a certain amount of extra expenditure. Having once defined these gradients for all parts of the system, by applying the same to the formula for the cost characteristic the whole problem as regards the programme of the alterations becomes very simple, and therefore helps considerably in settling the political and financial questions. In this way it will certainly be found that in large cities extensions with continuous-current generation are out of the question, and that Dr. Klingenberg. independently of existing continuous-current distribution systems the whole feeding system, and as far as possible the extensions of the distribution system, should be carried out with alternating current at as high a pressure as possible.

It has been pointed out in the discussion that in determining the factors bearing on the cost of electricity, I had overlooked the diversity factor. This is not the case. By referring to Fig. 4, which gives the load factors under any combination of light, power, and traction in large cities, it will be seen that these include the diversity factor, or to state it differently, that from these curves the diversity factor can be determined under any combination of traction, power, and light. For instance, under the conditions assumed for the diagram Fig. 3, viz. 25 per cent lighting, 25 per cent power, and 50 per cent traction, the load factor according to Fig. 4 works out to 39·3 per cent, which means that the diversity factor under these conditions is about 88 per cent. I am paying the greatest importance to the results shown in Fig. 4, as they form a step forward in the direction of positive knowledge and simplification on a most important point where such a wide field for guesswork was left. My statements as regards the costs for lighting, I admit, may be misleading. In saying that under certain conditions these costs were equal to those for power and traction, I wish to lay stress on the costs in the power station only, a difference of course coming in when distributing the small demands to private houses, as compared with the large supplies required for power and traction.

Mr. Seabrook has asked for further particulars in regard to the gasifying of coal in connection with the Berlin supply. Close investigations which were made some years back did not prove sufficiently promising at the time. The conditions may be different with new developments and if a power station of large capacity is erected on a coal-field in the vicinity of industrial centres. As the matter stands at present, this requires careful study in every individual case.

I entirely agree with Dr. Ferranti as regards the great prospect for electricity if this could be supplied at its "correct" price; but after a close study of the question in general and from my experience I am less optimistic about the time in which such progress will be made in cities. Past history has shown that the supply of electricity is not a highly paying business, in fact many companies are permanently suffering from their selling prices being fixed too low. Under such conditions it is not an easy matter to convince the public that this will be different in future and therefore to find the capital for proceedings on a very large scale. London appears to be situated not more favourably in this respect than other cities, in fact the comparison in Fig. 5 shows that the selling prices in 1911 were considerably below the cost which one would call a normal price, having regard to the capital charges. Even if the progress of the demand is taken into consideration, as I did with the numerical example of London (I assumed an increase of the demand in one to two years of about 28 per cent), I think such a problem generally requires careful study as regards the programme for the reconstruction before one is able to show an economical advantage at all in the near future,

Dr Klingenberg

and more so if no margin is left in the existing selling price for current.

In reply to Mr. Snell's remarks I wish to make it clear that I have not recommended for London the erection of a power station at the coalfields. I do not feel in a position to advance any recommendation at all on a subject requiring such intimate knowledge of very special conditions, about which only local engineers can judge. The object of my Address was merely to discuss generally the principles of electricity supply in large cities as they appear to me from past experience and with present knowledge. In applying these principles to a numerical example it appears natural that I should base this, as regards the main and initial assumptions, on such values as would approximately correspond to the conditions over here. The results I arrived at are therefore more or less mathematical and outside any political considerations.

As regards my calculations, Mr. Snell doubted the figure of 170s. per kilowatt installed which I arrived at for the distant power station, mainly in view of the difficulties of the water supply. I admit that I have assumed it to be possible in this country to find satisfactory conditions for cooling arrangements at or near the collieries, but taking the worst case, viz. that cooling towers would have to be installed, the above price still seems adequate and in accordance with the cost at which new stations on the Continent have been built. With regard to the consumption of water, I cannot imagine that there would be any difficulty in providing for this, even with a very large power station: it should also be borne in mind that the loss of water has considerably decreased with the improvement of the steam consumption, and I estimate that a new station with large sets would perhaps require only half the amount used in the existing London stations based on an equal output. Further, Mr. Snell has criticized the figure which I have allowed for land required for the overhead lines. 600s. per ha. was reported to me as a liberal allowance under the conditions. When considering this point it should be borne in mind that it will not be necessary to buy the assumed strip of 15 metres for the whole length as a freehold. At certain parts I expect it would be possible to lease the right for the pole lines on more favourable terms, and the freehold land could still be used to a great extent for general purposes. With this in view I believe that the amount which I have allowed can be considered as an approximate average figure, but even a considerable increase in this item would only mean a small percentage of the total cost which I have taken for the lines. I agree with Mr. Snell that this question of land forms a disadvantage in densely populated countries as compared, for instance, with the United States, and I may say that this is one of the reasons in my opinion why engineers in European countries should pay more and more attention to the use of high-pressure cables for long transmission lines. It is remarkable how small the difference in cost works out (see Figs. 9 and 10), when comparing overhead and cable transmission for a pressure of 100,000 o ts.

Mr. Snell has also touched upon the question of safety in the case of a supply from distant stations. This is certainly a very important point for an electricity supply to a city. I am of opinion that transmission over distances such as those on which I have based my calculations can nowadays be considered sufficiently safe, especially if a certain amount of plant is kept as a spare near the cities, which will most probably be the case in every large city for a considerable length of time. The possibility of using cables instead of overhead lines would no doubt improve matters still further.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF THE 18TH DECEMBER, 1913.

Proceedings of the 559th Ordinary Meeting of the Institution of Electrical Engineers, held on Thursday, 18th December, 1913—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 4th December, 1913, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

A paper by Mr. H. C. Gunton, entitled "The Employment of Power in H.M. Post Office" (see p. 109), was read and discussed, and the meeting adjourned at 9.55 p.m.

DISCUSSION ON

"A TWO-RATE TARIFF SYSTEM WITHOUT TIME-OPERATED CONTROL."*

MANCHESTER LOCAL SECTION, 18TH NOVEMBER, 1913.

Frith.

Mr. J. FRITH: In discussing this question it is well to consider what are the objects of a tariff. They can be broadly divided into two distinct categories. The first aims at doing justice to every consumer connected to the mains, *i.e.* endeavours to charge every consumer in some way proportionally to what he costs the supply undertaking. The second aims at obtaining the maximum financial success for the supply undertaking. Broadly speaking, the policy in the case of a municipal undertaking should approximate more toward the first, and that of a company to the second of these categories. It is hardly possible to explain to the lay consumer the meaning of the term "load factor," but it can be explained to him that if he wants his supply at the same time that everybody else is wanting it, it is only fair that he should pay more than if he were taking his supply at a time when other people were not using electrical energy. I think when we have decided which of the above aims we are trying for, a few of the other conditions of a good tariff are worth discussing. The first thing is that a tariff should be understandable by the customer. He should be able to estimate what the supply is going to cost him. The next point is, of course, that the tariff should encourage the free use of electricity. Personally, I think the tariff best adapted to do this is a fixed charge per annum and a small price per unit irrespective of the use made of the energy, but I am not quite sure how the fixed charge should be based. The rateable value method is simple, but it is not easy to see why an electricity bill should depend on the size of a garden. I wonder whether such apparatus as that described in the paper will give results which can be easily understood by the customer and which will gain his approval; it would be interesting to know if any such information is available.

Watson.

Mr. S. J. WATSON: I myself have not had any experience in the use of two-rate meters. The most important point to be borne in mind in framing any tariff is that it can be understood by the consumer. A few years ago many undertakings charged on the maximum-demand system, but I do not think that there are many to-day who continue to use that system. It was condemned because consumers could not understand it. It is doubtless quite correct in principle, but it is impossible to make various classes of consumers understand why one class should pay at a higher average rate than another. I feel convinced that for a general supply for domestic and similar purposes some method whereby only one circuit inside the house and one meter are required is the simplest and the best that can be adopted. It is only a question as to the basis of the standing charge. People know that the municipal rates are based on the rateable value of their property, and they know the rent which they have to pay; they can therefore tell approximately what their liability will be if the rateable value system is used. Some time ago the chief engineer of one of the London supply companies explained to me how very different are the conditions in the residential districts of London from those which obtain in Lancashire manufacturing towns. He pointed out that in order to sell as many units per annum as are used by a 5-h.p. motor operated during factory hours, it would be necessary to connect up about 150 small heaters or similar appliances on the premises of his domestic consumers.

Mr. Atchison.

Mr. C. C. ATCHISON: In Rochdale my experience is entirely different from that of Mr. Watson at Bury, as I certainly find that the public-house consumers are those who appreciate the maximum-demand system. It seems strange that two towns so near together as Bury and Rochdale differ in this respect, and it emphasizes Mr. Watson's remarks as to how much greater must be the difference between Lancashire and London with their entirely different problems. Mr. Watson also mentioned that the demand indicator appeared to him to be a correct method of charging. I cannot quite agree with him on that point, but whether the maximum-demand system is or is not correct it is certainly a very difficult tariff to use. It can be explained to the consumer and he may fully understand it, but at the end of the quarter when he receives his bill he has probably forgotten all about the explanation. In regard to the flat charge based on the rateable value with a uniform price per unit, the remarks this evening have called my attention to what appears to be a weak point in that system. Take the case of two houses of similar size supplied by electricity, one having no garden and the other a large garden; each may have identically the same number of lights and consume the same amount of electricity, but the man with the large garden, if charged on the rateable value system, will pay a larger annual sum than the man without a garden. Is it reasonable to make this difference in the price? As against this, I should like to call attention to Mr. Frith's statement that apparently the system of charging adopted by municipalities is equity and that of companies profit. Surely although we try to bring equity into it the municipality has also to aim at a profit; but whether we wish to bring in equity or not, a low price per unit is useful, no matter what other charge there may be. Possible consumers always quote the charges paid in other towns; and in almost every case, whatever the other rates may be, the lowest figure is stated as being the charge for the class of supply required. Only during the last few days the Bury tariffs have been quoted twice to me, and I may point out that the price mentioned by the possible consumer was only applicable after a certain number of units had been consumed at a higher rate. It will be seen that each one tries to bring in equity and at the same time look after the profit. If it is possible to state a low price per unit it is taken into consideration by the consumer and further

* Paper by Mr. H. H. Perry (see p. 42, No. 223).

hison. charges almost overlooked. Perhaps this idea is somewhat of a "catch-penny" business, but it pays in the long run.

Previous speakers have advocated one circuit for all purposes; in some ways I should do so myself as it is certainly convenient to have only one meter, but at the same time I should like to see a uniform price. There is quite enough to do without adding to the clerical work, as we find to our cost in Rochdale where we have 28 different prices to deal with; perhaps it is not readily appreciated how easy it is to increase this kind of work and how difficult it is to reduce it. While one circuit no doubt sounds the right thing, experience does not always prove it to be so. Probably all supply engineers know how a consumer who first installs a certain number of lights and later wants to add to these, naturally not wishing to spend more money than is necessary to provide the original installation, finds that his wiring is not sufficient and that it means starting from the service terminals and installing new wiring to the various points of the house where it is desired to increase the supply. This question is very closely allied to the undersized plug circuits; as a supply engineer I do not think it matters whether the undersized plug circuit is in order or not since this is a matter purely for the consumer and his contractor. If it were necessary to inspect all the installations in order to see that suitable sections of wire were used it would mean that a spare man would have to be employed, and even then we could not be quite sure without having a man permanently on the spot while the installation was being carried out; this of course might not be convenient. I think the present arrangement of leaving it to the consumer himself is the only reasonable method, as he will be certain to find out for himself sooner or later, and it remains then for the supply undertaking to refer him to the contractor who wired the installation. Also in regard to one circuit, in this paper a meter has been described which may be utilized for one circuit, but the author has been cute enough to provide also for two circuits, and the meter has been designed to meet the requirements—much as they appear to differ—of Lancashire and London. The whole question of tariffs seems to me to remind us that we have to get as much money as we can from consumers, and if there is any instrument that will ensure equity at the same time as profit we should endeavour to find it.

Hol-sworth. Mr. E. M. Hollingsworth: The author has put forward a very ingenious and no doubt quite practicable device, but I am afraid it has arrived too late in the day, for central-station engineers are rapidly getting away from the complicated and costly two-meter systems. In proof of this I would point to the general adoption of one or other of the "contract systems" which are proving satisfactory to the user and the supply undertaking alike. The author states that no paper on the subject of tariffs has dealt with the question of giving the consumer a lower rate during the light-load hours. Surely, a contract system does give such an advantage, and such systems have recently been the subject of several papers. I do not agree with the author in his reference, on page 43, to the diversity factor in connection with the supply for power. In determining the charges to large power users, the diversity factor plays no part; it is entirely a question of "value of service." To bring in such users, the supply authority has to prove that it is to their advantage to adopt the supply, hence the low charges at present prevailing. One of the advantages claimed for the use of the author's switch is that a consumer can tell what his cost per unit will be. It is my experience that the user is more concerned about the total cost per quarter or per annum than about the cost per unit; and in any case this system does not give the average cost. Mr. Hollingsworth.

Mr. P. P. Wheelwright: My experience of a two-rate tariff and two-rate meters, although I have only tried them on a small scale, is, I regret to say, far from satisfactory and bears out the disadvantages mentioned by the author. I quite agree that there are places where the system and apparatus described in the paper could be used with success, but I think that the following points ought not to be ignored, and in many towns are sufficient to prevent the system being put into operation. The use of lighting circuits for heating apparatus may lead to trouble and possible disaster, as after all when purchasing a small radiator or a kettle the consumer has only a very vague idea what the probable cousumption will be. Consequently when the radiator causes the fuses to blow, and lampholders and lighting plugs to overheat, considerable annoyance is caused and the supply department is called in, with the result that the consumer is notified that the wiring is not suitable for anything but small apparatus. The contract prices accepted during the last few years for wiring large installations bear out my contention that after all there are few houses where the double use of the wiring may be carried out with safety and satisfaction to the consumer. The question of satisfying the consumer that his meters are registering correctly, should he doubt it with this two-rate apparatus in use, is one that cannot be overlooked; personally I can see considerable difficulty in explaining any sudden increase in the higher priced units in a quarter's account. The suggestion that the capital outlay required to install this apparatus with an extra meter may be overcome by the payment of a rental is, I think, wrong. I maintain that the price of energy ought to cover the cost of the necessary measuring instruments, etc., as in all other trading concerns. At the present time I think most supply departments will acknowledge the difficulty in getting consumers to notify them of any extensions which they may make in their lighting installations or any increase in heating or other apparatus. Consequently where the instrument is in use it is very liable to be considerably overloaded, if not burnt out. I quite agree with the author that the simplicity in working is an advantage of the instrument, but simplicity in the method of charging for energy is the only point that the consumer really appreciates. Mr. Wheelwright.

Mr. A. G. Cooper: This paper takes me back many years. When I was with the City of London Company in 1892 I brought out a meter on practically the same lines as that described in this paper. The only alternating-current meter at that time was the Thomson meter, and I took out a patent for splitting the windings. The British Thomson-Houston Company bought the patent and I gave the foreign rights to the French meter company. Very few meters were sold. Unfortunately at that time all electric light stations were run on more academic lines than at present. The stations then were not content to know how much money they had to receive, but also wished to know what was the loss in distribution. The meter would not indicate whether one unit had been used for lighting at 6d., Mr. Cooper.

Cooper. or 3 for power at 2d. (I have assumed these prices.) I wanted to charge according to the rateable value and get rid of the meter; I therefore took about 40 consumers and found that the conditions in the different cases varied so widely that I came to the conclusion that no tariff could be framed to meet all cases. I also found that the demand indicator was disliked by the publicans. The only thing to do with the latter was to charge them all on the 3-hour rating, *i.e.* one hour at 6d. and two hours at 2½d.; they were then all satisfied.

Peck. MR. J. S. PECK: It would appear that the idea underlying Mr. Perry's instrument is that the off-peak load on the station can be increased by offering the consumer a low rate for his lighting, provided this is kept down to a small percentage of his usual load. It is purely a matter of opinion, however, whether there will be an increase in the net profit when it is considered that the increased load is supplied at a lower rate, and also when the extra cost of the automatic switch with the necessary maintenance charges are given due weight. In Fig. 4 an arrangement is shown by which the greater the power load the greater the lighting load which can be obtained at the low rate. This seems to me to be wrong in principle; for if it is desired to keep down the peak load, then the arrangement should be reversed so that the greater the power load at any time the less the lighting load which can be taken at the same time and at the low rate. In regard to the construction of the instrument itself, I should anticipate more or less trouble due to burning at the contacts; for while it is true that only a low voltage has to be broken at the switch, the forces for operating the moving element are very small, and it may happen that the switch can stick in the balanced position, thus causing an arc to continue for a sufficient time to do serious damage. In any case the switch in its present form would only be suitable for use with very small currents. The author states that there is a loss in the switch of 4 watts with continuous current, and of from 8 to 10 watts with alternating current. If the loss on alternating current is 8 to 10 watts, the number of volt-amperes across the switch will be several times that figure on account of the poor power factor, so that the voltage drop will be very considerable.

Wilkinson. MR. H. T. WILKINSON: I should be glad if the author would give us some examples of the actual operation of this switch in practice. I should like to have one or two instances; the prices applying to the two rates, and the average price obtained. When I was with the Lancashire Electric Power Company a few years ago we found it a great mistake to talk to consumers in terms of units. In one case one of our engineers was trying to convince a prospective consumer that 0·8d. per unit was a low price for him to pay. He could not impress this on the customer, so told him that in some places 5d. or 6d. was charged. The reply was that he did not know what a unit was, but 5d. seemed a lot to pay for one of them. The Acme Spinning Mill at Pendlebury, the first electrically-driven cotton mill in this country, was supplied at a fixed sum per annum for driving and lighting. We took on weaving sheds, and charged at so much per loom per annum. We found this worked out satisfactorily, the price of course varying with different types of looms.

MR. W. CRAMP: There is one very important point in this paper which has been barely touched upon, and deserves much more comment than it has received. It is to the effect that under the proposed tariff the smaller the amount of energy used the less is the price paid per unit. Consumers hitherto have been encouraged to take as much electrical energy as possible—when they have taken as much as possible for lighting, the supply authority offers a lower rate if energy be taken for some other purpose. Here, however, the author has suggested a system whereby the customer using lights only will receive a distinct advantage. The man at whom the author is aiming is he who uses a few lights for many hours. If this system were adopted, the electricity bill would be of this character; for a few lights, a low rate; for more lights, a higher rate; and for lights plus power, a lower rate again. Mr. Wilkinson is, I think, quite correct in stating that the rate for electrical energy should be expressed in a unit which consumers can understand rather than in an electrical unit. Take a flour mill for instance; if the cost of electricity can be expressed at so much per sack of flour produced, the miller knows just what is meant. Mr. Cramp.

I should like to say a word from the consumer's point of view about the two-circuit system of wiring. The fact is that a very small proportion of people own the houses in which they live, and consequently two cases are constantly arising: (1) If the landlord or the previous tenant has done the wiring, it is more than likely that the single system has been employed, and the new tenant has a strong objection to paying for the installation of a power circuit. (2) If the tenant has the whole wiring to do he grudges very much the cost of a double system which at the end of a short lease becomes the landlord's property.

A very important question which arises out of the paper is the cost of apparatus installed by domestic consumers to make use of the power rate. I refer to apparatus for cooking, heating, etc. The suggestion which the author makes in this connection "that the supply authority should have a hiring department" is a very good one, but in my opinion to charge for hire without maintenance would be a mistake. The fact is that domestic consumers experience very great trouble owing to the fact that there is so little standardization of parts of domestic apparatus, and also that the cost of repairs is so high. As an example, an electric iron may cost the consumer from 12s. to 15s. It may give trouble owing to the breakdown of the flexible wire or the burning-out of the heating unit. In the latter case on returning the iron to the makers it will often be six weeks before it is repaired, and the cost of the repair may be half the cost of the iron. So long as such cases occur domestic consumers will be necessarily shy of purchasing apparatus, but if they could hire it on a maintenance agreement they would be glad to do so. Such hiring with maintenance would lead to two very desirable results: First, in towns like Manchester the electric apparatus would be on a footing similar to the gas apparatus; and second, large purchasers like the supply authorities could bring pressure on makers to improve and standardize their wares. With regard to the difficulty of using domestic apparatus upon ordinary lighting plug circuits, I should like to say that if the lighting wiring has been installed to a proper specifi-

Cramp. cation there need be no fear at all of overloading the lighting plugs so long as not more than 1 kw. at 200 volts is used per plug. I consider that a great deal too much has been made of the danger of over-running wires and flexibles. It is quite possible, and usually quite safe, to take 1 kw. at 200 volts from an ordinary lighting pendant.

Barlow. Mr. F. BARLOW: I should like to ask the author if at the end of a quarter a check can be taken on the readings for the preceding quarter; if not, how is it possible to be in a position to enforce the charges should the consumer dispute them?

fessor rchant. Professor E. W. MARCHANT: Speaking as a consumer, I am of opinion that it is an advantage to know, approximately, how much one will have to pay at the end of a quarter, and I think that any system which leaves any doubt about it is not altogether satisfactory from a consumer's point of view. That seems to me the objection to the maximum-demand system, and to a certain extent to the system described by the author. I also have doubts as to how the working of the author's switch is to be checked. If the switch sticks, it seems to me that there might be a very heavy charge due to the high-rate meter. I should like to know whether there are any devices on the switch which will provide for such a contingency.

. Perry. Mr. H. H. PERRY (*in reply*): The origin of my idea first centred around the two-rate clock, which as a system has very distinct advantages and has given good results in practice where tried. The disadvantages mentioned in the paper, however, outweighed the claims of that system for general use. The advent of heating and cooking by electricity suggested that a two-rate system might be used if the switch could be automatically controlled; for there is this curious anomaly, that a relatively high price is charged for lighting and a very low one for heating. So long as the domestic consumer uses the supply, it matters little for what purpose he uses it—if light is not required at certain hours he may be induced to use the supply for another purpose. When the time comes for offering an average rate of, say, $1\frac{1}{4}$d. or $1\frac{1}{2}$d. per unit, then the central station can depend on a regular day load.

Mr. Frith referred to the desideratum of charging a fixed price and a small rate per annum. If all consumers are satisfied, this is an excellent plan. I am asked for information regarding the operation of this two-rate switch. It has only been tried experimentally, but it has been subjected to very exhaustive tests under the most varying loads. I am rather surprised that nobody has mentioned electric heating and cooking and the results therefrom. It seems to me that a new field has opened up rapidly, and it would have been very interesting if members had given their views as to the desirability of pushing this new departure.

Mr. Watson laid emphasis on the fact that whatever system was chosen it should be capable of being understood by the consumer, and he approved the principle of the maximum-demand system. I am perfectly in agreement with him there, but the system, as stated, has its limitations. If a flat-rate system can be adopted on a primary house assessment charge, it is possible to have one meter for the whole supply, with heating and lighting at the same rate, but the short-hour consumers with a high maximum demand, such as shops, derive too great a benefit.

Mr. Atchison laid stress on the clerical work side of the question, and in consequence generally prefers a primary charge system. I am afraid the clerical work must always be a trouble, and I do not see how it can be got rid of; but if extra business can be derived with advantage, this department must necessarily increase. He also raised the question as to the size of the contacts in the switch shown. They are quite large enough to carry at least 25 amperes. The instrument described will only have to carry a quarter of this load on the low rate, and I do not think there is the least chance of any trouble, since on the high rate, the greater the load the greater is the pull on the contact. The point where there may be trouble is at the position of equilibrium, but the auxiliary contacts are so designed that the switch is practically never broken. The switch operates equally well on either alternating current or continuous current. Mr. Perry.

Mr. Hollingsworth claims concessions for light-load usage by other systems, and while this is true for some of them, they do not bring that knowledge clearly to the consumer—as stated in the paper. I think he rather misses my point as to the diversity factor when domestic tariffs are considered. Here the power takes the form of heating or cooking, and is to-day a class of business eagerly to be sought after, and in a few years' time likely to cause a further revision of tariffs. Should this prove to be the case, the diversity factor will enter very largely into the calculations. As regards being late in the field with the proposed tariff, I am inclined to the belief that it may be too early.

Mr. Wheelwright asked for some information as regards the working of the switch, and he rather doubted the reliability of the same. He advocated that there should be no meter rent, and I quite agree with him if the rent can be omitted and its equivalent included in some way in the tariff. If the consumer doubts the sub-division of energy between the high- and low-rate meters, it should be a simple matter for the inspector to show the switch in action on a critical load for which it is set.

I am interested to hear from Mr. Cooper that he patented a single meter for two-rate use as far back as 1894—I was unaware of the existence of such a patent. He mentioned the question of lighting circuits being inadequate. As far as the general size of wiring goes for this system or any other, it is of course impossible to add heaters and use them indiscriminately over a house not originally wired for their inclusion. If large radiators or heaters are going to be used, it invariably means new circuits. This is one of the greatest troubles in persuading people to add to their existing circuits. It leads to obvious inconvenience and they hesitate a long time before giving their approval to a structural disturbance. I suppose time will show whether this expression of opinion is the same all over the country when electric heating and cooking are more generally adopted. When electric cooking is adopted, the present consumers' circuits need not be disturbed, since cooking is usually carried out in the kitchen or scullery near the meter, and only a very short length of additional wiring will be required.

Mr. Peck raised a point with regard to Fig. 4, and thinks the conditions as regards load on the opposing windings should be reversed. The argument may be amplified:— If a valuable consumer of power is to be encouraged, it

Mr. Perry. will be safe to give him better terms for his lighting, should his heating peak, if one only, not overlap the normal peak on the system due to lighting. If he had three peaks per day due to heating, as instanced at Derby, it would still pay the supply authority to allow one peak to overlap the lighting owing to the increased revenue from the day load. It is not suggested that the consumer should get the whole of his lighting at the low rate, but a greater proportion than in Fig. 3. Mr. Peck also raised the question of arcing at the contacts when the apparatus in use with the switch has a large self-induction. The switch has been tried under such conditions and found to work very satisfactorily.

Mr. Wilkinson asked whether the switch had been actually used in practice. Owing to the unexpectedly early date of this paper, I regret to say "No," but I hope in a very short time to give the results of actual working. As regards the rates proposed, the high rate should certainly not exceed that charged at present.

Mr. Cramp raised the question of the consumer with a large number of lights and whether he gets any benefit from the use of the proposed two-rate system. The object in view with the proposed system is to meet the rational demands of an ordinary household, irrespective of the number of lights. There are hours when only a few lights are required, but the majority are "necessitated" lights and are kept on for long hours—such loads are valuable and a low tariff is naturally offered. But household customs demand at other hours—all too few—a number of lights approaching the maximum, for which the generating station must be prepared every day. It is fair to charge a higher rate for a perfectly logical use. If the same consumer adopts heating or cooking by separate circuits, it is true that his average rate does decrease for the dual supply, since heating could not possibly make any headway unless a low rate were given—and its load factor should warrant the low rate. It is inconceivable that any ordinary consumer would designedly use only a quarter of his maximum number of lights in order to gain the low-rate charge.

The answer to Mr. Barlow's question is contained in the reply to Mr. Wheelwright, and, moreover, much the same contingency might arise with the instrument on the maximum-demand system. If it would facilitate matters, a counter could easily be fitted to the automatic switch, or a relay indicator placed in some conspicuous part of the premises to meet the requirements in special cases only.

In reply to Professor Marchant, the private consumer who is content to make regular payments for his supply, however used, would probably prefer the flat rate or the contract rate. Under the proposed system he would certainly pay no more, and very probably less. Owing to the decided gravity action, there is no tendency for the switch to stick on the high-rate side, other than fusing action; which contingency has already been discussed. The indicator would at once show a false position.

DISCUSSION ON

"THE CHARACTERISTICS OF INSULATION RESISTANCE." *

Birmingham Local Section, 26th November, 1913.

Dr. Garrard. Dr. C. C. Garrard: The characteristic shape of the moisture conductivity curve found by Mr. Evershed is of great interest, and in view of the microscopical and other researches given in the paper one is rather diffident of expressing any doubt as to the underlying theory of endosmose which seems to fit in excellently with the facts of the case. I should only like to ask the author if he has considered whether the phenomenon cannot be explained on the basis that the conduction of the moisture within the insulator is electrolytic in character. If two electrodes be placed in a vessel of water, and a gradually increasing voltage be applied, it is found at first that the current flowing is very small, but that after a critical value has been reached the current very rapidly increases, that is to say the electric resistance rapidly decreases. This phenomenon, with a single cell, only occurs between zero pressure and a pressure of, say, 2 or 3 volts, but in a porous insulator one can regard the moisture as being split up into a large number of cells in series, so that the pressure over which the action will be shown might be several hundred volts, as is the case in Mr. Evershed's experiments. On this basis could also be explained the fact found by the author that when the insulator is very wet the conductivity follows Ohm's law; for, with a very wet substance, instead of a number of electrolytic cells in series we only have one, and a variation in resistance over the first volt or two is of no effect when working with a pressure of several hundred volts. I do not put this theory forward in any sense as a rival of Mr. Evershed's, as I have not had an opportunity to put it to any experimental test. I merely mention it as an alternative suggestion. Possibly Mr. Evershed as a result of his prolonged work on the subject has sufficient experimental data to upset it. The electrolytic action might also account for another phenomenon which I have often observed when testing the insulation resistance of apparatus, and that is that it improves if the testing voltage be applied for a long period.

One outstanding feature of the paper is the impossibility of using porous insulating materials in electrical machinery. At the present time these are of course no longer used by up-to-date manufacturers. The fibrous materials such as cotton, paper, and the like, are used simply as mechanical carriers for the insulating compound. The experiments showing that even impregnated windings absorb moisture are remarkable. They do not, however, bring out the im-

* Paper by Mr. S. Evershed (see p. 51, No. 224).

rrard. portant point that although qualitatively a certain amount of moisture may be absorbed, yet quantitatively the amount is too small to do any harm. I am doubtful also whether the author's results are the best that can be obtained with impregnated windings when using modern flexible insulating compounds. I am also at a loss to understand why in his experiments on oil Mr. Evershed used cylinder oil. The results would have been more useful if good transformer oil had been used. The so-called "dry" oil of Fig. 21 was probably not really dry or I should have expected a larger change in the resistance. Tobey* has shown that 0·03 per cent, *i.e.* 5 or 6 drops of water per quart of oil, reduces the dielectric strength by 25 per cent. The dielectric strength is, however, not proportional to the insulation resistance. In fact the latter is of very little use in the investigation of the electrical properties of oil. These are much better studied from the point of view of dielectric strength against electrical breakdown.

I am not able to agree with Mr. Evershed's statement on page 64 that on evaporation the electrolytic ions generally remain behind. If the water be pure the conductivity is due to the electrolytic dissociation of the water itself into the ions of hydrogen, hydroxyl, and oxygen. These are in a state of chemical equilibrium with the water itself and evaporation does not affect the conductivity. If, however, there are dissolved salts in solution the evaporation of the water naturally increases the concentration of what remains and this will cause the conductivity to increase. I cannot but admire the author's resolution of the water into resistance water and dormant water. This conception will doubtless prove exceedingly fertile.

In the footnote on page 51 the author somewhat deprecates the application of flash tests to electrical apparatus. I have, however, to join issue with him on this point. In fact I have no great belief, as far as electrical machinery and apparatus are concerned—I am not speaking of cables—in specifications which call for an insulation resistance of a certain number of megohms. What the purchaser requires is an easily applied test which will ensure him a reasonable margin of safety against breakdown. In my experience a specification of insulation resistance will not give this. The only thing which will do this is to require the application of a test pressure for a more or less lengthy period. I think I can detect Mr. Evershed's influence in some of the specifications issued by the Engineering Standards Committee, especially those for instruments and meters, where standard requirements for insulation resistance are given which in my opinion are useless in ensuring that the purchaser will get a satisfactory article from the point of view of immunity from insulation trouble. I quite agree that on high-voltage machines too high a test pressure is not desirable and is apt to damage the dielectric. Nevertheless, in principle, the high-pressure test is the only reliable one. The chief advantage of the measurement of insulation resistance is that it enables us to discover bad places in the insulation, and by studying the variation in the insulation resistance from day to day faults that are developing can be localized. It is not possible, however, at any rate in the present state of the art, to guarantee on the basis of an insulation-resistance test only, that an electrical appliance has a sufficient margin of safety to stand up against the usual working practical conditions. A pressure test is much more useful in this direction and in my view should never be omitted. Dr. Garrard

* *Transactions of the American Institute of Electrical Engineers*, vol. 29, p. 1198, 1910.

Dr. G. Barlow: Another model of an absorbent insulator could be made by closely packing granules of a non-absorbent and highly insulating material, *e.g.* sand. The leakage paths in this case might be expected to represent the conditions in a porous material much more nearly than the parallel tube model used by the author. Measurements of the resistance of porous materials at temperatures low enough to freeze the condensed moisture might be of interest. In order to produce such solidification within the pores one would probably have to lower the temperature a long way below the normal freezing-point. Dr. Barlow

Mr. A. R. Everest: The author has described some very interesting investigations in connection with the objectionable change in insulation resistance of fibrous or moisture-retaining materials when tested with different applied pressures, but it is a little difficult to combine these new theories with the facts already known. Previous investigations regarding the changes in insulation resistance have been principally devoted to study of the changes with temperature. A paper was read before the American Institute of Electrical Engineers several years ago describing a research upon the variation in insulation resistance of fibrous materials with varying temperatures. The suggestion was made that the entrapped moisture exists at the lower temperatures largely in the form of disconnected particles, and that as the temperature is increased these particles split up into smaller particles, increasing the number of continuous chains through the thickness of the material, causing greater leakage, and accounting for the lower insulation resistance. Other investigations have shown that when a material of this class is subjected to a high-potential stress heating is produced, and this heating in turn by lowering the insulation resistance increases the leakage losses and causes still further heating. Disruptive breakdowns occur if the temperature is allowed to exceed a critical value for the material and potential gradient in question. If the material is kept cool by artificial means, higher pressures are endured without breakdown. A slot tube of cemented paper or similar fibrous material will have a certain breakdown value when tested on a tinfoil-covered wooden mandril, but will endure higher pressure without breakdown if a solid steel mandril is substituted. On the other hand, if the temperature is artificially raised, the potential gradient sufficient to cause breakdown is reduced. Again, if a mica barrier is placed so as to interrupt the leakage losses which cause the cumulative heating, much higher potentials can be endured without breakdown. This subject was discussed in Mr. Rayner's paper on "High-voltage tests and energy losses in insulating materials."* Perhaps Mr. Evershed would kindly indicate how far it would be necessary to modify his theory in order to take into account the effects of temperature. I should also like to ask Mr. Evershed if he has made any tests upon Bakelite or upon fibrous material treated with it. Insulation made up with this material shows a much smaller decrease in insulation resistance with an increase in temperature. Mr. Everest

Dr. M. L. Kahn: Mr. Evershed's paper is of great importance as it contains definite statements with regard to the Dr. Kahn.

* *Journal I.E.E.*, vol. 49, p. 3, 1912.

Dr. Kahn insulation resistance of electrical apparatus. I have always felt that this particular feature of electrical apparatus has not been investigated as much as it deserves, especially as the insulation resistance is often one of the qualities mentioned in specifications for electrical apparatus. It seems that there are two conclusions which may be drawn from Mr. Evershed's investigations. The first is that it is absolutely useless to specify any value of insulation resistance without stating the voltage at which the measurement is to be made. Although this has been recognized by many engineers, the majority of the specifications issued still omit to state the voltage. As the instruments by which the insulation resistance is measured are usually made to give 500 volts, and as it appears from Mr. Evershed's paper that in the neighbourhood of this particular voltage the insulation resistance is comparatively constant, I should like to propose that this voltage be adopted as a standard for testing insulation resistance, if this is to be specified at all. As the author has made all his tests up to this pressure, it appears that he also regards this particular voltage as a standard for insulation-resistance tests. The second point which is clearly brought out by this paper (although it has of course been well known to most electrical engineers) is that the insulation resistance of electrical apparatus is by no means constant, even if taken at a given voltage. The variations shown in Mr. Evershed's paper, although they are very remarkable, are often exceeded in electrical apparatus. The insulation resistance of such apparatus can sometimes be increased 10 times or more by a simple drying process. As the paper clearly shows that the insulation resistance entirely depends on the amount of moisture suspended in the insulating material, and as this is something foreign to the actual apparatus and can be altered without altering the apparatus in any other respect, it is quite clear that the insulation resistance is not an intrinsic feature of the apparatus and should therefore be entirely abolished from all specifications. The insulating properties of such apparatus can always be clearly proved by the usual pressure tests. Insulation tests will of course always be very useful to determine the state of the insulation of any apparatus at a particular time, or to show if the apparatus can be subjected to flash tests after it has, for example, been standing about for some time.

Mr. Turner. Mr. E. O. TURNER: There seems to exist at present great difficulty in judging the relative merits of similar pieces of insulating material tested by different experimenters. Apparently the puncture test is the only one which gives at all consistent results. On page 61 the author points out that if a test-piece is carried through a standard course of vacuum baking and varnishing, its insulation resistance after some time settles down to about a fairly steady value. I should like to ask the author whether the succeeding variation of resistance can be represented as at all a definite function of the humidity of the air. Were this the case the insulation resistance, dew-point, and temperature might be measured simultaneously at a fixed voltage. A correction could subsequently be made to a chosen standard of humidity. It would be of interest to know if the author can hold out any hope of forming a basis for comparison of results obtained in this way for test-pieces of uniform size. Referring to Fig. 1, it seems possible that at the final part of the curve, near the breakdown point, there might be an appreciable rise of temperature in the moisture channels—if these still persist—due to the concentration of the energy loss in a minute volume. In this case the extremely high negative temperature coefficient of water might account for the rapid drop in the curve. As published figures on this subject are scanty I have drawn up the following table, giving resistances in megohms per centimetre cube, to show how large the variation is. Mr. Turner.

Temperature in degrees C.	15	20	40	60
Pure water (containing no CO_2)	37	25	8·5	5·0
Distilled water	0·45	0·24	0·11	0·06
Tap water	0·014	0·012	0·008	0·005

A local rise of temperature before puncture has been noticed, particularly in high-voltage alternating-current tests. It seems possible that with low voltages also a small effect of the same kind might be observed.

Mr. W. C. S. PHILLIPS: So far the results of Mr. Evershed's work seem to show that a good non-absorbent insulator obeys Ohm's law. In the case of absorbent insulators, the current is not proportional to the voltage, the irregularity being due to the presence of water—a substance which does obey Ohm's law within certain limits. In order to explain this apparent paradox the author suggests that the exact mechanism of conduction is by electric endosmose. I should like to know if the author has conducted any experiments on paraffin wax, as I consider it desirable that his theory should be tested on substances which can be melted in vacuo. Some recent work by Swann* may be of interest in connection with this paper. He has worked at a potential gradient of 50,000 volts per cm. The method adopted by him was to enclose the paraffin wax between two metal plates A B (see Fig. A) Mr. Phillips.

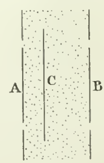


FIG. A.

which were surrounded by guard rings. The third plate C was completely immersed in the paraffin wax, which was heated for some time to 120° C in vacuo and then allowed to cool. The plate C was nearer to A than to B. The method of experiment consisted in earthing all three plates and guard rings, removing the earth connection and then momentarily charging C to a high potential. This was done by passing a wire from a high-potential battery to the edge of the disc C through a hole made in the wax. On removing this wire the hole was filled up by locally melting the wax with a hot wire. Surface leakage was

* *Philosophical Magazine*, vol. 26, p. 678, 1913.

hillips. thus completely eliminated. The rate of motion of the needle of an electrometer connected in turn to A and B was then noted, and it was found that when C was positively charged, the plate A acquired a positive charge and B a negative charge. If the substance between the plates obeys Ohm's law there should be no change in potential of either A or B. This was shown to be the case where the wax was replaced by paraffin oil. Thus the electrometer only shows that portion of the current which does not obey Ohm's law, and in some of his experiments Swann calculates that the current so observed is about 60 times the current calculated by means of Ohm's law. The total current taken by the wax is some function of $\frac{dv}{dx}$, the slope of potential. I should like to ask Mr. Evershed if he considers these anomalous results are to be explained by his theory.

orrest. Mr. F. FORREST: The effect of temperature upon the insulation resistance of non-absorbent insulators such as rubber and gutta-percha is very pronounced, and with both materials a rise in temperature is immediately accompanied by a serious fall in the insulation resistance. The author does not deal with this important point in his paper, and it would be interesting to have his views on this matter. Gutta-percha cable when submitted to an external pressure (as occurs when it is laid at the bottom of the sea) shows a marked increase in insulation resistance, whereas the samples of paper tested by the author (see Figs. 14 and 15) showed an equally marked decrease with an increase of pressure. Can the author explain this difference in behaviour? The only really satisfactory method of testing the insulation to earth of an electrical machine is by means of a flash test carefully carried out at a pressure several times greater than the normal working voltage to earth. This flash test will show up weaknesses in the insulation to earth which could not be discovered by any other method.

hed. Mr. S. EVERSHED (*in reply*): Dr. Garrard suggests that the moisture curve might possibly be explained by supposing the absorbent insulator to act like a number of electrolytic cells in series. This hypothesis occurred to me at an early stage of the research. It was the subject of a long series of experiments which all went to show that the curve was not to be explained in that way. To mention only one of the stumbling-blocks we encountered: If the curve connecting applied voltage with the apparent resistance V/I of any number of electrolytic cells in series is investigated, it will be found that R_v/R_{nv} varies from infinity at the beginning of the curve to unity when the applied voltage is enough to swamp the back E.M.F. This follows at once from the equation for the current in a cell, and is independent of the value assigned to the voltage ratio n. But the most marked feature of the moisture curve is that when once the applied voltage exceeds the back E.M.F. of a single cell by a few volts, the ratio R_v/R_{nv} settles down to a nearly constant value, which it retains over a wide range of voltage. In other words the cell curve and the moisture curve follow entirely different laws. Quite apart from experiment, however, the hypothesis of cells in series breaks down the moment we ask ourselves where and what are the electrodes of the supposed cells? As regards the water-in-oil experiments, my only object was to ascertain whether in that case water gave a typical moisture curve or not. The fact that the cylinder oil already contained some water did not prevent the experiments from answering the question with a decided negative. Dr. Garrard and I do not really disagree about the effect of evaporation on the conductivity of electrolytes; all that the statement in the paper means is that in most cases it is dissolved salts which provide the majority of the ions. Mr. Evershed.

If Mr. Everest will refer to the moisture curves given in the paper, and reckon the electrical power spent in heating the various things that were tested, he will find that in no instance did the power exceed a small fraction of one watt. The fact is that throughout the whole of the moisture curve, right up to the point of inflexion, heating is quite inappreciable. It is only when we come to the second part of the complete characteristic curve and the breakdown point is rather closely approached, that heating becomes a serious factor.

Dr. Kahn suggests that we should standardize the testing pressure. Surely the only reasonable standard to adopt is one based on the voltage at which the apparatus under test is intended to work. There is no particular virtue in 500 volts, but the investigation of the moisture curve has been carried out with that pressure as a maximum, simply because it happened to be the ordinary limit of our testing battery. I am providing a pressure of 10,000, and possibly 20,000 volts (continuous current) for the investigation of the breakdown part of the complete curve.

Replying to Mr. Turner, an absorbent insulator is an excellent hygrometer, but the cost of the necessary testing apparatus is a serious obstacle to the adoption of this method of determining the humidity of the air.

I was much interested in Mr. Phillips's account of Swann's experiments on the resistance of paraffin wax. It is difficult to believe that there were any cracks in the wax, and still more hard to believe that there was any water present to find its way into the cracks if they existed. Hence it is hardly likely that the decrease in resistance with increase in pressure was caused by endosmose.

Several speakers have defended the flash test on the score of utility. I have not denied the utility of a pressure test; on the contrary I regard high-pressure tests as essential to the maker of electrical plant. What I deprecate is the blind way in which such tests are generally conducted. What should we think of the civil engineer who, having built a steel bridge for a railway, ran on it as many locomotives as he could collect and then shut his eyes? The engineer who knows what he is about applies the load, measures the deflection, and notes the set when the load is removed. It is time we electrical engineers put our pressure tests on the same basis. To do that involves nothing more than the use of a high-tension continuous-current dynamo, with some kind of current indicator or resistance indicator to give warning of latent defects in the insulation under test.

Western Local Section, 1st December, 1913.

Mr. H. F. Proctor Mr. H. F. Proctor: From what the author has said it seems to me that in adopting a pressure test it is reasonable that such pressure test should be applied for a short period only, but I also think it desirable that all high-pressure tests should be applied after the normal working pressure has been applied for almost an unlimited period of time. The endosmose effect is thus obtained under working conditions by applying the normal pressure and maintaining it, after which the high pressure should be applied with a view to ascertaining whether a breakdown results by adding the extra pressure. I should like to ask the author whether any experiments have been made to ascertain results with tests carried out by alternating current? Of course, as the author has said, continuous current should always be used for such tests, but it seems to me quite conceivable that alternating current may give, and from the paper does give, at any rate to a certain extent, the endosmose effect, where I presume the capillaries are very small. I think it would be interesting to have some further information upon the matter, because so many of us, of course, deal with alternating current alone. I should also like to ask with regard to the oil used for transformer work. A good deal has been said about the use of oil for saturating materials, and varnish, and the results obtained, but I think it would be interesting if the author could tell us anything about oil in its bulk form as used for transformer purposes. Have any results been obtained as to absorption of water by oil, also are there any ready means for testing oils to see whether water is present or to see whether oil is of such a nature that it is liable to absorb water? Some time ago I had occasion to carry out an experiment in connection with the introduction of iodine into the human system, and I rendered the process visible by passing the iodine through gelatine. The transference of the iodine was very evident. I take it that the introduction of iodine into the system by electrical means (Kataphoresis) is practically the same thing as endosmose, and it appears to me just possible that experiments may have been carried out by the author as regards the transmission of water through oils. I think that information on this point would be a matter of very great interest to those of us who have to use transformers.

Professor Robertson Professor D. Robertson: Mr. Evershed's conception regarding the processes which take place inside a moist material, aided as it is by his ingenious model, must be of the greatest value to those who have to study the subject closely. The constancy of the ratio in his characteristic curves is very remarkable, as is also its agreement with that determined for his capillary-tube model. Attention might be drawn to the fact that the value of 2·15, which is given as the average deduced from Mr. Rayner's tests, corresponds very closely with the simple law that the insulation resistance varies inversely as the cube root of the testing voltage. In connection with Figs. 8 and 9, it does not seem quite justifiable to term the whole of the variable part of the current "charging current." If the properties of the material did not vary with time, there would of course be a charging current in addition to the leakage current at the moment of switching on, but even with a battery resistance of several megohms a few seconds would suffice to reduce this to a negligible amount. Actually the material goes on yielding with time, and we have the phenomena of absorption and residual charge which make the charging current die away much more slowly. Here, at least, the author would seem to assume that all the change is to be ascribed to the capacity effect and none to the resistance, although in his experiments with his model he both observed and explained changes in resistance with time as well as with voltage. Of course what he here terms the "leakage current" does represent the actual leakage that would be found with continuous-current working, but it would probably have no more meaning for alternating-current apparatus than the usual "after one minute's electrification." The author's explanation of the action of his model is beautifully simple, but almost too good to be true. The action of a potential gradient on the positively charged water would be to exert a force on the whole length of the film, and it is not evident why that should produce any effects such as those indicated in Fig. 27. With a uniform field the force would be the same all along the film, and would produce a bodily movement without any accumulation at some particular place. To account for the thickening of the film in this way it would be necessary to assume that the potential gradient is concentrated at the positive end, or that the friction is less there than elsewhere. An increase of pressure of the main body of water at the positive end would not force the water into the film, but would flatten the end of the bubble, contrary to the observations. The author's theory gives a somewhat doubtful explanation of the film effect, and none of the end effect. A complete explanation would have to deal with the air-water surface as well as with the glass-water one, and would have to take account of the changes produced by electrification on the effective amount of the surface tension. An increase of the curvature at one end, as observed at the positive end A, indicates the occurrence of one or both of two things, viz.: (1) An increase of the excess pressure of the inside over the outside of the air bubble; (2) a diminution of the surface tension. A flattening of the end, as at the negative end B, indicates the reverse of these changes. The first suggestion would require a negative volume change in the air bubble or in the main body of the water, or both, in order to produce the right pressure changes, and it offers difficulties in accounting for the entrance of water into the film at a place where the pressure is reduced relatively to the inside of the air bubble. Surface tension always tends to pull the surface into as small an area as possible, at least when the surface separates a liquid and a gas. An electric charge on the surface, on the contrary, tries to repel it out as far as possible, and that action is the same whatever the sign of the electrification. Consequently the observed surface tension is practically always less than the real surface tension, because separating surfaces are nearly always electrified, and materials in contact are at different potentials when they are in equilibrium. If, as in a capillary electrometer, we make this potential difference differ from its normal value, the effective surface tension will be decreased or increased according as we have increased or decreased the opposing electrical action. In our model we may

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suppose that the battery makes the water at the positive end more positive than normal to the air inside, and at the other end less positive. If, then, the water is normally positive to the air, in accordance with the author's statement on page 68, the application of the battery will increase the electrification of the positive surface of the air bubble and decrease that of the other end. This would reduce the effective surface tension at the former, and increase that at the latter, and the result would be exactly the changes of curvature which the author describes. We have still to account for the water forcing its way into the film when the potential difference is applied. For this purpose we must consider the outer surface of the film. The surface tension there tends to draw the water over the surface, but the tension of the air-water surface inside, in its endeavour to take the spherical surface of minimum area, tries to squeeze the film out. The thickness of the film is determined by the equilibrium of these two actions. Consequently, the reduction of the effective tension between the water and air at the positive end of the air bubble enables the external tension to force more water into that end of the film when the battery is switched on. At the other end we should expect some of the film to be squeezed out, which is neither contrary to what the author says, nor supported by his experiment. We may reasonably suppose that the electrical conditions change gradually from one end of the bubble to the other, and that they will also change with time as the film grows. In fact, the growth of the film will have the effect of concentrating the potential difference on the thin end, thus carrying with it the region of reduced surface tension, giving the "wave-front" which the author mentions. It is not by any means to be expected that the expulsion of water from the negative end of the film, if it does take place in accordance with the theory here given, will amount to as much as the water taken in at the other end, for it is known that surface tension is greatly modified when the films are very thin. The alterations produced by electrification on the surface tension of the air-water surface are thus sufficient to account completely for the way in which the bubble and film behave, and they do so much more satisfactorily than the theory propounded in the paper. It must not be forgotten, however, that the real value of Mr. Evershed's model in assisting us to understand the actions in a moist insulator does not depend upon the correctness of his own particular way of explaining why it acts as it does. The appendix on insulation valves is to be commended as a clear exposition of the cause of polarity and valve effects in moist insulators.

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Mr. W. A. CHAMEN: This is a most valuable paper but difficult to discuss. One naturally thinks of the effect of moisture in alternators. I suppose that the ideas we have hitherto held that porous insulators if kept at a high temperature, as they nearly always are in electrical machinery, are quite safe for working, are not wrong. The information obtainable up to last June was to the effect that we had nothing whatever to fear from the use of wet-air filtration. I suppose we are still right in assuming that while the temperature of the porous insulator is kept fairly high, say to 200° Fahr., we have nothing to fear from the absorption of moisture. I rather gather that the only insulators which are not porous, so far as the author's experiments have gone, are india-rubber, gutta-percha, and perhaps one or two substances of that nature. We have been accustomed to look upon porcelain perhaps too much as a non-absorptive material, particularly if well glazed. The author's experiments with porcelain are therefore most instructive. With regard to the last part of the paper, I am reminded of a very peculiar occurrence in Glasgow some years ago. A continuous-current triple-concentric cable had broken down. The positive conductor was in the centre, then came the negative conductor, and the neutral was outside next to the sheathing but of course insulated from it. All three conductors were disconnected from the source of supply and a test was made by connecting through a lamp any one of the "dead" conductors in the first case with the positive pole of the supply; the lamp immediately glowed to full brightness but rapidly dropped down to a dull red. The connection was then suddenly reversed so as to connect the "dead" conductor with the negative pole of the supply; the lamp at once glowed again with full brilliancy and then began dropping down to dull red. This test was repeated several times, always with the same result. The fault was found to be in the neck of a cast-iron joint-box, where the lead sheath of the cable was taken in. It was intended of course to make a really substantial metallic bond between the cast-iron box and the lead sheathing of the cable, for the purpose of conducting back any currents that might arise through breakdown. The jointer, however, had wrapped around the lead, where it passed through the gland of the box, a most elaborate system of mica sheets, which of course left capillary passages right through the gland from the damp earth outside to the interior of the box. I have always thought it was moisture getting in between the sheets of mica which gave us that extraordinary effect, but have never found time to try experiments to prove it. I do not know whether what the author has told us about his porcelain test is quite a parallel to what I observed. I think his case differs from mine because the insulation of the porcelain appears to be always high in the one direction and low in the other, while I found low insulation in each direction to start with, which insulation immediately rose. Mr. Chamen

Mr. A. N. MOORE: Last summer I made some careful investigations of wet-air filtration, and also discussed the subject with engineers who had already adopted it. I learnt that in one case where a wet-air filter had been installed the insulation resistance had immediately decreased, but it decreased only to a certain point, and for some nine months afterwards; the humidity being kept constant, the insulation resistance did not vary under ordinary conditions. Whether there is a limit to the amount of moisture absorbed by the insulating material in the case of a highly insulated high-tension machine or of any ordinary generator, and whether the presence of moisture really matters, provided the quality of insulating material is such as to render any breakdown unlikely, assuming the factor of safety is not exceeded, and that the limit in the amount of moisture present necessary to bring about a breakdown has not been reached, are questions which naturally occur to one. Mr. Moore.

Mr. J. L. WILSON: In connection with the bottom part of the curve in Fig. 1 where the material is approaching the breakdown point, it would be interesting to know what kind of recovery the material makes when that point is Mr Wilson.

Mr. Wilson. reached. Information regarding the behaviour at that point will be of the greatest practical interest when the author has concluded his investigations. With regard to the "valve effect" which the author mentions, most of us know of this phenomenon and when making tests it is usual to take two readings with the terminal connections reversed. It is surprising to find such a large difference, which is much greater than any I have experienced.

Mr. Walker. Mr. S. F. WALKER: I am in full agreement with the author's remarks in the first part of his paper, and I should like to mention that what he has given us in such detail in the numerous curves that are distributed throughout the paper, practical electrical engineers have known, though not in such detail, for a very long time; indeed, since the early days of electric light. I remember at a meeting of what was I think then still "The Society of Telegraph Engineers and Electricians" there was a discussion upon the insulation of cables. I have forgotten the exact subject of the paper, but I remember that I opened the discussion by pointing out that the practice which had been common up till then and which was advocated in all the text-books, of measuring insulation resistance with a battery of comparatively low pressure, was wrong. I pointed out that if accurate results were required, results that would be of any use in laying out plant, the insulation must be tested with at least the pressure that was to be employed when the cables, etc., were in use. To my surprise I was followed by a number of practical men, telegraph engineers and others, who had had to deal with the same problems, and who had found the same results.

I am also in hearty agreement with Mr. Evershed in condemning "blind tests of breakdown voltage." I have always considered that while it is wise to know all about a cable, by testing a representative portion of it to the very utmost, and breaking it down, it is very unwise to subject to a very much higher pressure than the working voltage a cable which has subsequently to be employed for transmitting power. It has always appeared to me that it is impossible to prevent the insulation being strained, thereby decreasing the final value of the dielectric as an insulator. What the author has also worked out in such detail, viz. the effect of moisture, is what we were all aware of, though we had not the figures before us: we did not know anything about the curve that he has given, and we merely knew that the presence of moisture lowered the resistance of any insulator, and that the more moisture we allowed to get in the lower was the insulation resistance. I do not think many of us knew that the moisture was also subject to the effect of the higher pressure, although most of us were aware that with higher pressure we got a lower insulation resistance. The work which Mr. Evershed has done and the constants that he has worked out will be of great value.

One of the greatest difficulties with which electrical engineers have to contend, is the expansion and contraction that take place with variations in temperature. Unfortunately, we cannot avoid variations in temperature; and these expansions and contractions will always cause the openings for moisture that the author has discovered. His experiments remind me again of my experience in the very early days of the use of electricity in mines. I remember the trouble which I had in keeping moisture from moving contacts. It was not possible to lead wires or cables through glands, so closely embracing them that moisture would not penetrate; and it was only possible by providing very wide flanges to enclose contacts so that moisture did not reach them easily. Water vapour, and water itself, have very aggravating tricks. For instance, a crack in a casting that is practically invisible to the eye is quite sufficient to allow water to find its way through to contacts which the casting is intended to protect. What I used to call the "capillary dodge" is made use of. The water assumes the form of vapour, passes through the crack in that condition, and condenses on the inside. I found that the only way to cheat moisture was to give it a very long path, by having very wide flanges as carefully machined as possible. I suggest that some of the peculiar phenomena which Mr. Evershed has found in the tests given in Table I are due to what I may term the interaction of air and water. My work in connection with refrigeration, heating, and ventilating, together with a close study of the waywardness of steam, have shown me some of the tricks which air and vapour together will perform. For instance, air has a capacity for absorbing water vapour, which capacity increases very rapidly with the temperature; and consequently it may easily happen that a small body of air is carrying a comparatively large quantity of water, a certain portion of which it will deposit immediately its temperature falls. On the other hand, water evaporates at all temperatures, and whether it will evaporate or not depends upon, as I think is well known, the difference in the tension of the vapour issuing from the water and that present in the air. It will be found, I think, that a similar set of phenomena take place with the vapour of oil and water, and air; I suggest that further experiments should be carried out on those lines. All mineral oils, it will be remembered, are more or less composite bodies and will give off vapour at different temperatures. In the conditions under which electrical apparatus has to work, it is never certain when the temperature will rise and when vapour will be given off. Hence it appears to me that what may be termed interaction may take place between the vapour of the oil used for insulation, the water vapour, and air. If a fall of temperature follows a rise of temperature it may easily happen that there is a space left, into which air may penetrate carrying water. I also suggest that the peculiar action which the author has found, that only a small portion of the water present in the test pad of filter-paper upon which he experimented takes part in varying the electrical resistance, is due to the action of the air. I suggest that interaction is going on there, between the air and the water vapour.

There is another very interesting series of phenomena in connection with liquids, which the modern science of chemical physics has investigated. The majority of liquids will dissolve practically all gases; and when a gas is dissolved in a liquid it gives up its latent heat of gassification, the temperature of the solution being raised in consequence. Further, the ability of any liquid to dissolve any gas decreases fairly rapidly as the temperature rises. This fact is taken advantage of in one of the methods employed in refrigeration. It appears to me again that the oil in the liquid state which is present in paper, or as the insulation for transformers, for instance, may alternately dissolve air and water vapour and drive them out, according as the temperature falls or rises. The whole matter is very complicated; it demands a large

amount of study and a great deal of careful experimenting to investigate it thoroughly, and I for one heartily welcome the work which Mr. Evershed has done. I hope that he will continue it.

I have for a long time wanted to carry out an extensive series of experiments upon cables. My idea has been to obtain a number of lengths of representative cables and to submit them to varying pressures; to test them periodically, and at stated intervals to strip portions of them. I think that what we want to know is what is taking place inside cables subjected to different pressures, both continuous and alternating. There is one other point which is worth consideration and which I think the author has not mentioned, viz. the osmotic action of a continuous current. I think it has been found that the action is present even with alternating currents, owing to what may be termed the resultant current. Osmotic action must take place wherever currents are passing, and it will introduce still another factor into the equation.

Mr. E. B. VIGNOLES (*in reply*): I am placed in rather an unfortunate position in having to reply to the discussion which has taken place, not being myself the author of the paper. It deals with a very complicated subject, and the matter is almost as new to me as to members present. Anything I now say therefore must be taken rather as my own personal view than as being authoritative answers to the questions raised.

Mr. Proctor put one or two points. First, whether the resistance of dielectrics was usually constant. I think the curves in the paper will show that as far as Mr. Evershed's observations go, dielectrics, when there is no moisture in them, do behave in that way, that is to say there is no fall of resistance with increase of pressure. Mr. Proctor further suggested that high-pressure tests should only be applied for a short time and after the material has been subjected for a long period to normal pressure. Mr Evershed's view with regard to high-pressure tests is that if such tests must be made then it is most desirable that there should be in the circuit during their application some means of knowing what is the result of what is being done. Mr. Rayner showed in London a method which he had developed for ascertaining that, and it impressed me as being very useful. He subjects the material to an alternating pressure, say 2,500 volts, and in series he has a milli-ampere meter with a battery which has to pass a small continuous current through the insulation material superposed on the alternating current. The alternating current is doing the breaking down of the insulating material, and the continuous current is showing to what extent it is being broken down. He showed us curves obtained by this method, which were extremely interesting, but it appears only applicable to that part of the characteristic curve where the insulation is on the point of breaking down. Mr. Proctor further asked whether tests could not be carried out by means of alternating current. The difficulty is to get an instrument which is sufficiently sensitive. I imagine that is the reason why these experiments have never been carried out with alternating current. The absorption of water in oil is not dealt with in the paper.

I was very much interested in the remarks of Professor Robertson on the explanation of the phenomena which Mr. Evershed observed under a microscope. I am quite unable to discuss such a complicated matter on the spur of the moment, but no doubt Mr. Evershed will have something to say to it when he comes to write his reply to this discussion. Mr. Chamen alluded to the moisture in absorbent insulators which are kept more or less constantly at a high temperature. It seems to me that if the temperature is above boiling-point of water, it would be impossible to have condensation of moisture. [Mr. Chamen: I suggest about 200 degrees, which would be below boiling-point of water.] If below boiling-point I should say there would be some moisture condensed, but less than at lower temperatures. The phenomena observed by Mr. Chamen on cables were interesting, but I could not follow them in sufficient detail to suggest any explanation. There may have been something in the nature of valve effect there, but I doubt it. It looks more like an effect of capacity.

As to the recovery of resistance of the material on the lower part of the characteristic insulation curve, I think Mr. Wilson's remarks are interesting, and when Mr. Evershed comes to investigate the breakdown part of the curve, recovery no doubt will be one of the phenomena to be taken into account.

Mr. Walker pointed out that the general trend of the phenomena shown by these curves was known. Of course, that was so; Mr. Evershed points that out in his paper. But I do not know that I ever saw the complete curve before. It is quite possible that it has been published, but I have never come across it. Mr. Walker pointed out that years ago the question was under discussion whether the working pressure ought to be used in making tests of insulation. That is quite familiar to me. In 1889 Mr. Evershed introduced a testing set for that very reason, namely, that he realized that the tests must be made at the working pressure. He therefore introduced means by which that could be done. I was pleased to note that Mr. Walker expressed approval of Mr. Evershed's condemnation of blind high-pressure tests. It seems rather brutal to subject the insulation to a strain which it may not be called on to bear, unless by so doing it is possible to diagnose what, if anything, is wrong with the insulation. It is quite possible that means may be devised for making high-pressure tests really useful, but I believe it is a fact that at present there is no instrument which can give us such information regarding the result of the alternating-current high-pressure or "flash" test as to justify it from the scientific point of view.

Mr. EVERSHED (*in reply, communicated*): I need only add a few words to what Mr. Vignoles has said, several of the points referred to having already been dealt with in my replies to the discussions in Birmingham, London, and Manchester. Professor Robertson's alternative explanation of the phenomena we have observed in a capillary tube under the microscope, is of course quite new to me, and I confess not a little difficult to grasp. It seems at first sight to add yet another complexity to what Professor Miles Walker has aptly termed the unruly phenomena of insulation resistance.

Manchester Local Section, 2nd December, 1913.

Mr. Welbourn.

Mr. B. Welbourn: I have already taken part in the discussion on this paper in London, but there are one or two further points to which I should like to refer. While the results given in the paper belong to the first part of the curve in Fig. 1, the author says that he is making arrangements to investigate the lower or breakdown part of the curve. This matter has attracted a good deal of attention, and I am rather inclined to think that the problem is not very complicated. It seems to me that as the number of megohms decreases, the watts lost in the dielectric heat up the moisture and air and disperse them until a conducting path is formed which allows sufficient current to pass to char the surfaces of the conduction tubes. I would ask Mr. Evershed in his reply to this discussion to say what he thinks of this theory unless he prefers not to commit himself at this stage. One great value of this paper is that it gives us a mental picture of what is happening in an absorbent insulator. I now have quite a working conception of the distribution of dormant and conducting moisture, and of the way in which they mingle and again separate under varying electrical conditions. In regard to temperature, the author explained at the Institution that it was not necessary to keep the specimens under uniform temperature by artificial means, because there was no measurable increase due to dielectric losses. I would now further ask if the tests described in the paper were taken at a uniform atmospheric temperature. In regard to testing, the author refers to the usual test-room method of measuring the insulation resistance of absorbent materials after one minute's electrification. We only regard this as a qualitative test because of limiting factors of time and space. Referring to the footnote on page 51 regarding the flash test, my difficulty is this, I do not see what test we are to substitute in the case of any insulator having absorbent qualities to prove if the particular apparatus will withstand the sudden pressure rises to which all electric circuits are subject. I should like to ask if the author has any practical alternative in his mind to substitute for the flash test.

The tests set out in the following tables have been made to show the differences which exist between good and bad paper-insulated lead-sheathed cables. The continuous-current pressure was applied for five minutes and then the cable was allowed to recover completely before the next higher pressure was applied. The readings at 11·7 volts are only approximate because of the small scale deflection of the galvanometer, and are from one conductor to the other one "earthed."

Test on 7/17 S.W.G. Low-tension Concentric Cable at 14° C. Good Cable.

Volts	Insulation in Megohms per Mile after						Percentage Electrification between 1st and 2nd Minutes
	¼ Min.	½ Min.	1 Min.	2 Min.	3 Min.	5 Min.	
11·7	122	204	367	612	—	916	40
55·9	121	199	362	582	—	1,090	38
214·0	116	204	349	—	737	972	—
315·0	114	194	338	555	—	884	39
428·0	102	191	327	523	655	825	37·5

Test on 7/16 S.W.G. Low-tension Twin Cable at 13·7° C. Cable insufficiently dried.

Volts	Insulation in Megohms per Mile after						Percentage Electrification between 1st and 2nd Minutes
	¼ Min.	½ Min.	1 Min.	2 Min.	3 Min.	5 Min.	
11·7	802	129	188	254	306	350	26·0
29·8	87	101	130	160	171	183	18·7
98·0	60	67	77	85	88	90	8·9
428·0	40	42	47	50	50	51	5·9

Both these cables stood a pressure test of 4,000 volts (alternating current) for 15 minutes. The "percentage electrification" columns are worthy of study, while the figures for the insulation after 1 minute and the different behaviour of the cables at 428 volts are highly suggestive. A cable showing the characteristics of the second cable should not be used despite its passing the pressure test. It is also very interesting to find how curves of the same

general form can be obtained by raising the temperature of an absorbent insulator either by heat from outside or by applying a high alternating-current pressure. If the insulation is measured every half-hour and the results are plotted, the curve will be of similar shape to those obtained by the author, and the ultimate time of breakdown can be predicted from an inspection of the curve.

Mr. A. P. M. FLEMING: In addition to the exceedingly interesting mental pictures of the conducting process in absorbent dielectrics described by the author, there are two outstanding features in the paper, namely: (1) The fact that in the so-called absorbent dielectrics the insulation resistance is governed almost entirely by the conductivity of a small portion of the absorbed moisture. (2) That the insulation resistance of the dielectric diminishes according to a more or less definite law as the voltage at which it is measured increases. While most of us who have had to deal with the subject of insulation have been generally aware of these characteristics, I think that very few have appreciated their magnitude as clearly as has been set forth in this paper. I have only one criticism to make in connection with the measurements recorded—I can find no mention of the temperature conditions under which the investigations have been carried out. It is possible that the author's familiarity with the importance of temperature in connection with insulation-resistance measurements has led him to assume that everybody equally appreciates its importance. I mention this matter because one often finds engineers making comparative insulation-resistance measurements, especially on machines, quite irrespective of temperature, unaware of the fact that a few degrees' difference in temperature may alter the insulation resistance a hundredfold. I think that probably the cable-makers will have many interesting things to say about the paper itself, since insulation resistance plays an important part in their products. Viewed, however, from the standpoint of the manufacturer and user of electrical machines, I hope that the really good work embodied in this paper will not be misinterpreted to be other than valuable research work which will serve as a stepping-stone to a better knowledge of the properties of dielectrics, and that the paper will not be loaded with more than it is intended to bear. Ten years or more ago, it was usual for buyers of electrical machines to endeavour to safeguard the quality of the insulation employed by specifying a high insulation resistance. Similar machines might be called upon to show a resistance of 20 or 200 megohms according to the ideas of the buyer—who, however, often neglected to specify such refinements as whether the measurement was to be made with the machine hot or cold—and to get such figures the manufacturer had carefully to dry out his machine often to the point of mechanical disintegration of the insulation. Nowadays, the modern counterpart of that machine would undergo no such treatment, and the insulation resistance, if measured at all, would be found to be probably of the order of a megohm or less, according to the size and voltage of the machine. A machine under these conditions is likely to run just as safely and have a far greater life. Electrical manufacturers and most users have in the meantime realized that the real value of the insulation-resistance measurement is to afford a rough indication of the dryness of the materials and of the cleanliness of exposed surfaces. The resistance measurement does not detect mechanical flaws, and, moreover, if it were possible to do away with all solid insulation and space the conducting parts away from ground by an air-gap of, say, a few mils, the insulation resistance would be infinitely high, but the machine would fail under normal running voltage. On the other hand, a pressure test does serve to pick out local weaknesses such as mechanical flaws, and in a limited way also indicates the sufficiency and quality of the insulation employed. A far better way of ensuring satisfactory insulation is to insist on a rigid examination of the design, materials, and workmanship employed during the different processes of manufacture, and rely on this rather than on an insulation test. As distinct from cable work, there are in electrical machines so many alternatives, insulation paths, and such a variety of mechanical defects possible, that there appears very little prospect of obtaining an instrument suitable for detecting incipient faults, prior to actual breakdown. Further, if such faults could be detected, it would probably be better in most cases to produce a definite and unmistakable failure by means of a breakdown test, since the repair has to be effected in either case.

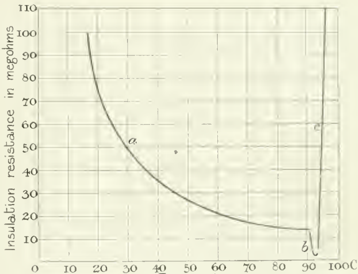

FIG. B.

In describing the behaviour of the ingenious model insulator, the author is able to show how the process of moisture dispersion goes on. This process is most important, and a number of cases occur in practice which bear out his interpretation of the phenomenon. I have in mind the behaviour of some large 50,000-volt transformers which were dried out prior to pressure testing by circulating hot air through and around the windings. The insulation was measured between the high-tension and the low-tension windings and earth from time to time as the temperature was raised, and the curve shown in Fig. B herewith was obtained. The part marked "*a*" represents a drying period of about 12 hours during which time the temperature was raised from normal to about 95°. The temperature was maintained at about this point for 72 hours, during which time a further marked decrease in insulation resistance as shown by the part "*b*" of the curve was obtained. At the end of this time the insulation

ning.

resistance rose very rapidly to a very high value beyond the range of the measuring instrument. In the first of these stages the moisture begins to be expelled into the main conducting channels; in the second stage this process is continued and completed, and in the third stage the moisture becomes evaporated from the insulation. The insulation consisted of fibrous material impregnated with insulating varnish, and these drying tests were carried out prior to the immersion of the transformer in oil.

From a number of pressure tests that were made, it was found that during the stage represented by "*a*," the apparatus just failed to meet its specified pressure test. During stage "*b*," the insulation failed at a considerably lower voltage, and during stage "*c*" the pressure test was withstood without any trouble whatever. These curves are generally typical of all windings insulated with fibrous material, and in addition to illustrating the dispersion of absorbed moisture show that a certain amount of drying may actually weaken the insulation as regards its ability to withstand a pressure test: it is only when the drying has been carried beyond a certain stage that any benefit is obtained. I should like to know whether the author has tested the absorption of moisture by materials impregnated with varnishes of the linseed-oil base variety, since, with such varnishes, expansion of the base occurs as the solvent is dried out and oxidation proceeds. One would expect in such cases that the absorption would be less marked than with other types of varnish. I should also like to know whether the author has compared such tests with those obtained on materials impregnated with solid bituminous compound, under vacuum. While such compounds have a considerable coefficient of expansion, and moisture absorption is likely to occur due to the "breathing" action which takes place with changes in temperature, my experience has been that such treatment affords greater immunity from moisture absorption than the usual varnish treatment. With reference to the typical conduction curve shown in Fig. 1, I note that the material employed was cotton in its undried state. I venture to think that had a composite dielectric such as is ordinarily employed for the insulation of electrical machines been used, the point of inflexion would have taken place with a potential gradient of the order of say five times greater than that shown, and while the first part of the curve would probably not have changed its shape to any great extent, the ultimate disruption would have occurred at a very much higher voltage, and the first and second portions of the curve would have been joined by a more or less straight and nearly horizontal line, this portion indicating a fairly wide range of potential gradient over which the conduction is approximately stable. A pressure test can be safely applied to such insulation provided it falls within, what has been predetermined by experiment to be, the stable portion of the curve.

fessor lker.

Professor MILES WALKER: Those engaged on the insulation of electrical machinery are greatly indebted to Mr. Evershed for this work on absorbent insulators, because he has succeeded in reducing to law and order a most unruly set of phenomena. Those who have had to do with fibrous insulators have always regarded the insulation resistance as something so uncertain and changeable that they had given up hoping that any law would apply, and they therefore trusted more to puncture tests, which are somewhat less uncertain, though still far from being satisfactory. The experiments that relate to the fraction of the moisture in a moist specimen which takes part in the conduction are especially interesting. I, in common with many other people who have observed the serious way in which a microscopical amount of moisture affects insulation resistance, would have thought that if anything the water present had more than its normal conductivity, but it appears that on the contrary only a few millionths of the water present does the work of conduction. One wonders whether the cases calculated by the author would have given the same results if the water used had not been of such a low specific resistance. If, for instance, the pad of blotting-paper had been moistened with pure water of very high specific resistance would not the insulation resistance have fallen by an amount almost as great as in the specimen cited. If so, the calculation as to the amount of water taking part in conduction would be upset. One knows that when moisture is distilled from the atmosphere it greatly lowers the insulation resistance, notwithstanding the fact that it may be very pure water. It would seem as if water spread in thin films on cellulose surfaces sometimes had a higher conductivity than the same thickness of film would have if regarded only as pure water. There is one point that is not explained in the paper. Why should we have an almost constant ratio (about 2) between the resistance at 50 volts and the resistance at 500 volts? Assuming that the theory put forward by the author is correct, we still have an enormous number of variable conditions which one would expect to alter the ratio. Such things as the different nature of the materials, which would affect the surface tension, the different shapes of surfaces, which would affect the amount of endosmose, the conductivity of the film, and the variation of the potential gradient as a function of the applied voltage. If the author can explain how it is that notwithstanding all these and other variables we might expect to get a constant ratio such as he has shown to exist, he would go a good deal further to establish the theory which from his results seems to have a good deal of probability behind it.

Professor Walker.

Mr. J. S. PECK: With regard to the various "moisture" curves, I should like to know how long a time elapsed after the voltage was applied until the resistance measurement was taken, as I understand from Mr. Welbourn that if a certain voltage is maintained on a dielectric the insulation resistance decreases with time along a curve exactly similar to those shown in the paper. Does this apply only when a certain critical voltage is reached, or does it apply for any voltage? If it applies for any voltage, I do not see how the curves given in the paper can be determined unless a very great time has been allowed to elapse between the different points in the curves. As to Fig. 1, I should like to know if, after the critical point in the curve has been passed and the voltage is maintained constant, the insulation resistance gradually drops to zero. As to the "barbaric" flash test which has been referred to, the Megger is often used to show whether insulation is in proper condition before subjecting it to this test. We know, for instance, in any line of machines that if the insulation resistance is much below a certain average value the insulation is in bad condition, and it will not be safe to test it under those conditions: we then use some method of

Mr. Peck.

Peck. cleaning the surface or drying out the insulation to make as sure as we can that the insulation is in a sound condition before applying the flash test. In my opinion the greatest value of the paper lies in the clear mental picture which the author has given of the action which goes on in a dielectric under stress. To me, and I think to the majority of engineers, a mental picture is of far more value than a mathematical formula.

Beaver. Mr. C. J. BEAVER : I think it is clear that the characteristic curve of cotton is also characteristic of all absorbent materials that are capable of holding water in an interconnected cellular structure.. The author has dealt fully with the first part of the curve in his paper, and promises future investigation of the third or breakdown part of the curve. I think that the second part of the curve depends largely for its length and angle on whether all the moisture has been driven out of the material or otherwise put out of action. In the presence of moisture, what happens during this part of the curve is that the moisture becomes electrolysed, and the electrolytic products formed will tend to produce paths of comparatively low resistance through which current will pass until the conditions merge into the third part of the curve by incipient charring. A great deal depends on the amount of moisture present. If moisture is absent, breakdown can only be caused by dielectric stress. To take the other extreme, a dielectric which is sodden with water is extremely difficult to break down under a high-voltage test, because the dielectric behaves like a high-resistance conductor. Several speakers have referred to the flash test, and as there appears to be some confusion of ideas on the subject, I think it is necessary to draw a distinction between the flash test as used by machine and transformer builders, and the high-pressure test as used by cable-makers. A flash test usually consists of a very short application of a very high pressure, whereas the other consists in applying a high pressure for a long time. In cable tests any required amount of "trim" can be provided at the cable ends, and precautions can be taken against the possibility of brush-discharge effects causing breakdowns at the ends. Machine and transformer builders have no such facilities for virtually extending their terminals, and under their testing conditions therefore the time element can only be allowed to enter into their test to a limited extent. The flash test therefore should not be utterly condemned, because it has well-defined uses. For accurate determination of breakdown pressures, however, the time element must be provided for.

The form of curve which is stated in the paper to be characteristic of moisture phenomena applies only to those substances containing water which are of such cellular character that the water can move in the capillary passages. Figs. 21 and 22, which relate to cylinder oil containing moisture and undried oil-impregnated paper respectively, afford a clear demonstration of this point. In the former case we have a homogeneous mixture in which the water though capable of being concentrated electrostatically is not capable of being driven in definite paths. In the latter case the oil has not displaced the moisture in the paper, and the sample therefore behaves like any other substance of cellular structure containing water. The subject of moisture in impregnated paper as used for cable insulation has been mentioned both by the author and one or two other speakers, and I gather that an impression exists that all moisture is not expelled from the paper in manufacturing paper-insulated cables. In the interests of accuracy this impression really must be corrected. Before impregnation, paper contains a certain percentage of hygroscopic moisture, but its vegetable structure does not contain any constitutional or chemically combined water, *i.e.* it consists of celluloses, and not cellulose hydrates. The hygroscopic moisture is easily expelled by heating, and the paper is then in a perfectly dry condition physically and chemically. Brittleness is not produced by over-drying, as has been stated, but by over-heating. Perfectly dry impregnated paper is not brittle ; in fact, it can be easily demonstrated that its tensile strength and elasticity are appreciably greater after impregnation than before. In conclusion, I think the broad lesson which the author's results have demonstrated is that all absorbent insulators have their limits of application. They would appear to be permissible in cases where the first part of the author's characteristic curve merges into a horizontal line, *i.e.* where the conditions are such that absorbed moisture can be readily expelled under working conditions, the limit in such cases being the dielectric strength of the material. If the moisture is not expelled we shall get electrolytic effects rapidly leading to breakdown at much lower voltages than would be represented by the dielectric strength of the moisture-free material. The combination of absorbent insulators in series with non-absorbent insulators naturally forms a compromise which for many purposes would be found quite satisfactory. Mr. Beaver

Mr. W. CRAMP : If there is one thing that stands out in this paper more than another, it is the keen sense of order of magnitude displayed. There is no attempt to drag in last decimal points where results do not sanction such a procedure. This is a lesson which we ought all to take to heart when writing papers which are called scientific or technical. I must differ from Professor Miles Walker on the use of the word "hysteresis." "Hysteresis" means simply "lag," and has intrinsically nothing to do with energy. The loss due to electrical and magnetic hysteresis is an energy loss, and thus the word is sometimes assumed to refer to energy only, without any real justification. Lag, and in particular cyclical lag, is denoted by the word "hysteresis" as a phenomenon. The energy corresponding thereto should not be called hysteresis only, but hysteresis energy, or hysteresis loss. On page 56 the author draws attention to two diagrams, Figs. 8 and 9, and he points out that the "one-minute electrification test" is really no measure of anything at all. It seems to me that the effect of this paragraph will be to change entirely the specified tests of cables or machines now subjected to "one minute's electrification." I would ask the author to suggest in place of the "one minute's electrification" some test giving a more satisfactory indication of the insulation properties. On page 57 the author says "leakage through dielectric rubber is nothing, leakage at the fittings is everything." This is perfectly true under the conditions mentioned in the paragraph, but, in testing a cable, leakage through the rubber is just what should be measured. For when all surface leakage has been got rid of there remains the necessity for a test on the rubber or paper to make sure that particles are not present which may conduct. I agree entirely with what Professor Walker has said regarding the shape of the resistance-pressure curves. It seems Mr Cramp.

mp. to me that the explanation put forward by Mr. Evershed is ingenious and correct as far as it goes. But it is well known that in capillary tubes the spaces between the dormant masses are filled with vapour of the fluid and that fluid can conduct; in this case there is no reason why conduction should not go on in the vapour as well as along the films.

In considering the insulation of electrical machines the use of enamel suggests itself. It is well known that conductors have been covered with flexible enamel for certain purposes. If the conductor of a dynamo were enamelled before it was otherwise insulated, would it not help very much to solve the moisture problem which the author has put forward? Sometimes insulation can be arranged in such an open way that it is possible to get air currents right through the various layers. In such cases the paper suggests that a better insulation test would be obtained than if the air spaces were filled with non-conducting material. Does the author agree with this? Recently a motor was supplied to me which was supposed to have a temperature rise of 75° F.; but on test it showed a rise of 94° F. When I objected, the manufacturers pointed out that they knew the motor was to be installed in a damp place and they had designed the machine with this temperature rise to counteract the atmospheric conditions. Such an excuse, though really indefensible, does seem to be suggested by the paper; and it raises a very interesting point, viz. Is insulation when in a condition of high resistance nearer to its breakdown or further from it? If the latter, then a case for a high temperature rise in damp situations is made out.

Mr. R. G. CUNLIFFE: The main factors affecting the value of insulation resistance, given in order of importance, are the effect of moisture, the effect of voltage, the effect of polarity, the effect of mechanical pressure, the physical structure of the material, and the extent to which the material absorbs moisture. In many standard cases absorption tests are specified in addition to flash tests and tests of insulation resistance, and in some cases flash tests are carried out with the insulator under mechanical stress. The test results given by the author are all obtained by the application of low electrical pressures, and it would be of interest if results were given for higher pressures, especially for extra-high-tension insulators such as porcelain, mica, etc. No mention is made in the paper of the effect of time. Are the characteristic curves shown in Figs. 2 to 23 obtained after definite time intervals for each application of pressure? If so, what are the intervals, and what is the variation in insulation resistance with time, for a definite constant pressure? If a model insulator be constructed by filling a glass trough with fine sand and placing two metal electrodes at the ends of the trough the resistance is found, ultimately, to increase owing to the moisture being driven from the positive electrode by endosmotic pressure. Fig. C herewith illustrates the case and shows the variations of the potential gradient at all points between the electrodes. The full line represents the gradient at the moment of switching on, and the successive broken lines the shapes taken by the gradient curve as the time of application of the pressure increases. It would appear from the test results and materials used that the author has not caused the moisture in the samples to flow bodily, but that there are reservoirs continually supplying the pipe lines formed by the conducting paths. Probably the conditions are different for solid bodies and sand or powdered insulators Mr. Cunliffe. and possibly different again for fibrous bodies where the fibres themselves are not impermeable to moisture. The loop referred to in Fig. 2 as the hysteresis effect certainly represents an interchange of energy, the air bubbles in Fig. 27 being compressed whilst the electrical pressure is applied and expanding when the pressure is removed.

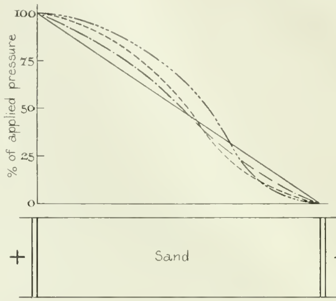

FIG. C.

The relatively immense frictional resistance at the walls of the capillary channel produces the time-lag observed. The constant, the value of which is marked on the curves, is very interesting, and an explanation of the reason for the particular value would be of interest. Possibly if experiments were carried out with very dilute solutions of standard electrolytes forced into the insulating material, other values of the ratio would be obtained which might indicate the reason for the particular values.

Mr. G. HUTTON WILSON: This paper is of special interest to Manchester engineers as the words "Manchester," "cotton," and "dampness," are almost synonymous. I have had to dry out a number of armatures and have often found that after stoving all night the insulation resistance is very low when the armature is still hot, but shows no leakage as soon as the armature has cooled down. Probably this is due to surface moisture which evaporates as the hot armature is brought out into the cold air. The author has clearly proved that moisture is always present in windings of every kind, whether varnished or not, and yet the insulation resistance to the frame may be as high as 10 or 20 megohms. Deterioration of the cotton covering of windings, such as field coils and armatures, is generally regarded as the effect of heat and moisture, and I can only call to mind one insulating material which is not deteriorated by heat and moisture. This insulation is aluminium oxide, and instead of causing deterioration, heat and moisture can increase its value, thus having a preserving effect instead of a deteriorating one. Aluminium field coils were referred to in a student's paper last year by Mr. A. T. Robertson.* In a footnote to that paper it was stated that the deductions as to aluminium coils were purely theoretical. Aluminium coils, however,

* *Journal I.E.E.*, vol. 51, p. 859, 1913.

are now a thoroughly proved success and are used very extensively on the Continent, in addition to a number of coils now in service in this country both for tramway and other work.

Mr. Crellin.

Mr. H. M. CRELLIN (*communicated*): With reference to the author's theory that the shape or form of the characteristic curves showing the relation between the dielectric resistance and voltage is due to the presence of moisture, I would point out that this apparent decrease of dielectric resistance with increase in testing voltage was shown by Appleyard, in a paper read before the Physical Society,* to be due to imperfect contact between the dielectric and the electrodes. With voltages up to 750, and tinfoil electrodes pressed against the dielectric by rubber discs loaded with 22·3 grammes per sq. cm., he obtained a curve similar to those described by Mr. Evershed as a "typical moisture curve." Increasing the load on the electrodes to 543 grammes per sq. cm. the dielectric resistance was found to be practically constant at all voltages up to 750. Further, on trying mercury electrodes (unloaded) a practically constant resistance was again obtained at all voltages up to 750. Further proof of this explanation is afforded by the results given in Section 6 of Mr. Evershed's paper, in which the author states that several kinds of oils and varnishes were tested, and "in every case Ohm's law was followed, the resistance proving to be a constant quantity." Again, in Section 8 of the paper, two cotton-covered wires after being wound on a porcelain bobbin and impregnated with varnish by the vacuum method were found to have a constant resistance at all voltages—results due, in my opinion, to the more perfect contact obtained between these dielectrics and the electrodes. Then why, it might be asked, does this last test piece (impregnated cotton-covered wires on porcelain) after 9 days' exposure to the air give a "perfectly normal moisture curve"? The key to this is given in the last paragraph of Section 8, viz. expansion and contraction of the windings—causing imperfect contact between the electrodes and the dielectric, or, more probably, crevices in the dielectric, which, by interposing air-gaps give the same effect of apparently lower resistance at the higher voltages. With reference to Fig. 16, it might on first thought seem that contact between the electrodes and the dielectric at such high loadings as 30 to 40 lb. per sq. in. should be perfect enough, but it must be noted that Appleyard found that 543 grammes per sq. cm. (7·73 lb. per sq. in.) was necessary to establish satisfactory contact with far more flexible electrodes than those used by the author. The more rigid copper plates used by the author cannot be regarded as sufficiently flat to exclude all air-gaps from between the electrodes and the dielectric, and thus ensure perfect contact at all points between the surfaces of the dielectric and the electrodes, particularly so in view of the experiments of Dr. Shaw on the Disruptive Voltage of Thin Films, the results of which were given in a paper read before the Physical Society,† in which he found, using the electric micrometer, that such a small air-gap as one micron (= 1/25,000 in.) will withstand a pressure of over 200 volts, and that $1\frac{1}{2}$ microns of air will withstand nearly 300 volts before breakdown across the gap occurs. Whilst I heartily congratulate the author on the large amount of really useful information which he has given us as regards actual test results obtained in practice on various windings and apparatus, I disagree with his theory that the apparent decrease of resistance with increase in testing voltage is due to moisture, the phenomena being, as Appleyard puts it, merely a surface effect that can be greatly reduced, if not entirely eliminated, by ensuring perfect contact with the electrodes.

Mr. Atkinson.

Mr. L. B. ATKINSON (*communicated*): In view of the fundamental importance of "insulation" to electrical engineers, and of the much smaller attention which "insulation" has received than "conduction," the paper by Mr. Evershed is a welcome opportunity for an exchange of views thereon. The paper is of a twofold nature; first, a record of careful experiments with all kinds of materials, extending over several years; and, further, the author has for the first time indicated, and to my mind proved, the cause of the phenomena observed with the majority of commercial insulating materials. His explanation of the variation of insulation resistance with the applied voltage is a permanent addition to our stock of knowledge, and should form the starting-point for improvements in insulation. He must also be congratulated on the clear mental picture of what takes place in insulating materials. It has long been known that insulators were of two classes—homogeneous, such as rubber, wax, and glass; and heterogeneous, such as cotton and air, paper and oil, etc., and though the superiority of the former has been recognized, the requirements of thin layers of flexible materials have led to the wide adoption of the latter class. It may be useful to complete the mental picture the author has given us by considering the structure of such materials and their bearing on the problem. The materials such as cotton, paper, press-pahn, and the like, are composed of natural cellulose matter, the growth of plants, and like all such cellulose matter are the solid matter composed of carbon, silica, etc., forming the framework in which cells of protoplasm have once lived. These cells, depending on the material, are of all sorts of sizes and shapes. In the case of cotton-seed fibres the cells are single filaments, and the envelope forms a tube with a fine hole through it; in the case of wood-fibres the cell coatings are of almost round, hexagonal, or other shape. These cells are very minute. From an approximate measurement I have made under a microscope, a fibre of cotton measures about 1/5,000th part of an inch in diameter, and the central bore averages perhaps one-third of this, or say 1/15,000 in. in diameter, *i.e.* 0·0016 millimetre.

We speak of these materials as hygroscopic. Now what do we mean by a hygroscopic substance? We mean that at a given temperature when the vapour pressure of water in a space is less than the saturated pressure corresponding to such temperature, water condenses on such a material. To what is this due? Partly, apparently, to the nature of the material, and partly, as Lord Kelvin suggested in 1870, to its form. Thus glass will have a layer of moisture on it at a temperature at which shellac will not. The quantity of water in the normal film of moisture on glass above the condensation temperature has been measured by Mr. W. H. White to be equivalent to a uniform film 0·00001 cm. thick or about twice as thick as the film measured by the author as existing in the tubes of his model. This film has apparently some connection with the chemical attraction of glass for water, all glass being soluble in water. But

* *Proceedings of the Physical Society of London*, vol. 19, p. 724, 1905.
† Ibid., vol. 20, p. 289, 1906.

ison. apart from hygroscopic substances of this class which depend on the low vapour pressure of hydrates, there is the hygroscopic property arising from "form." When we have to deal with minute liquid surfaces such as are presented by very fine drops, the vapour pressure on such a surface at a given temperature is higher than that on a plane surface; when we have a concave surface the vapour pressure is lower than that on a plane surface. Consequently if any film of moisture exists in a tube or spherical cavity of small internal radius, further moisture will condense at a temperature at which the air is not saturated with moisture. In a spherical cavity one-millionth of a millimetre in radius, *i.e.* 1/500,000 mm. in diameter, the vapour pressure at a given temperature is halved; in a tube of the same dimensions the effect is half that of a spherical cavity, and this lowering of vapour pressure is inversely as the diameter. If we take the case common in England of a temperature of 55° F. and an air saturation of 81 per cent, then the saturation vapour pressure being 0·433 in. of mercury, the actual vapour pressure would be 0·349 in. of mercury. In order that the vapour may condense, the surface on which the vapour condenses must have a reduced vapour pressure in the ratio of these numbers, and this, if a spherical cavity, will be 1/100,000 mm., say 4 millionths of an inch. Comparing this with the dimensions given above of the bore of a cotton thread, it is clear that if the hygroscopic property is due to the condensing effect of the small radius of curvature of cavities it is not that of the main cavity. But it may be that this main cavity has openings through the cell wall of smaller dimensions, and that to these the observed effect is due.

The author remarks, "when condensation takes place on the surface of a solid body, it first makes its appearance to us in small detached drops, etc." This may be true of its visibility, but if the substance is one which water wets, then probably this is the secondary effect. A uniform film is first deposited, slight unevennesses cause differences of surface tension, and the film breaks into drops. The case cited by the author of the drops on a spider's web is a case of this kind. It is possible, therefore, that the mechanism of the hygroscopic property and of the formation of plugs and layers of water in the fibres required by Mr. Evershed's theory is as follows: The exceedingly fine perforations of the thread admit moist air, and by their form and dimensions they provide a surface of lower vapour pressure and condense a layer of moisture. This by surface tension is drawn into drops that fill the cross-section of the tube with a plug and leave the film in between the plugs. It may be that the explanation of why we do not succeed in filling the material with oils and varnishes is that these materials are too dense and viscous to enter the capillary bores, and even water would be were it not that it evaporates and enters them in a gaseous form. And the re-appearance of the moisture curve in dried and oil-impregated materials may be explained by the absorption of moisture by the oil, its transference thereby to the surface of the cellulose material, its re-evaporation there, and its entering in gaseous form and recondensation in the still unfilled capillary openings.

shed. Mr. S. EVERSHED (*in reply*): I agree with Mr. Welbourn that the phenomena of the breakdown part of the characteristic curve are not likely to be so complicated as those of the moisture curve, but I think it would be rash at the present stage to assert that the rise of temperature, which begins to be appreciable as the curve approaches the breakdown point, is due solely to the power spent by the leakage current in the moisture films. Referring to the curve in Fig. 1 it will be noticed that by the time the region of inflexion is reached the potential gradient is quite high enough to produce a brush discharge from one electrode to the other. Here then is a far more dangerous mode of heating already at work. Mr. Welbourn asks me to suggest some alternative to the pressure test. I have dealt with this question in my replies to the discussions in Birmingham and London, and will only now add that Mr. Welbourn has answered his own question as regards paper-insulated cables. He gives us the tests of two cables both of which passed the pressure test, and both would doubtless have been passed as satisfactory, but for the significant fact that one of them betrayed the presence of too much moisture by giving a typical moisture curve. It is obvious from the figures in Mr. Welbourn's table that at the end of the 5th minute the charging current had not entirely died away, but it was already quite small compared with the true leakage current and the figures for the 5th minute may be plotted as voltage-resistance curves without much error. The tests on the concentric cable are rather discrepant and the ratio R_{2v}/R_{100v} can only be stated as somewhere between 1·1 and 1·35, but the other cable gives an excellent examp e of a moisture curve with a ratio R_{2v}/R_{100v} of about 3; a useful test, made with our eyes open, and telling us something about these cables which the pressure test failed to disclose. But for all that I would not abandon the pressure test. I only want to improve it.

Mr. Fleming raises the question of temperature as affecting the tests recorded in the paper. Air temperatures were invariably noted; but as a general rule no appreciable change took place during the course of a set of observations on a test-piece, the temperature of the experimental room being fairly uniform. Occasionally a protracted test might begin and end at temperatures differing by three or four degrees, but I have rejected all such tests if there was any likelihood of the temperature change masking the significance of the experiment. Any appreciable rise of temperature due to heating by the leakage current was obviously out of the question; take, for example, the curve given in Fig. 2. At 500 volts V^2/R is just 1/40th of a watt and this was being spent in the armature of a 20-kw. dynamo! As to the various test-pieces, none of them had less than 30 or 40 sq. in. of radiating surface, quite enough to dissipate a small fraction of a watt without any appreciable heating. As regards local heating, rise of temperature in the moisture films, I can only give the conditions in the model insulator. Reckoning from the curve given in Fig. 28, and counting only the area of the external surface of the films (the surface next the glass) the power spent at 500 volts was at the rate of 0·0035 watt per sq. in. Hence the film might possibly have risen in temperature by a fraction of one degree C., if it had not had the glass to cool it.

Replying to Professor Miles Walker the dormant water experiment was originally carried out with distilled water, and gave much the same values for the proportion of resistance water. The result was so unexpected that we

Mr. Evershed. repeated the experiment with a water of much higher conductivity in order to be sure that it remained substantially unchanged throughout the test. Professor Miles Walker cannot be more astonished than I was at the constancy of the ratio R_{7}/R_{107}. It actually constituted a stumbling-block to rational experiment because no matter what change was made in the experimental conditions the moisture curve remained practically the same. However, in the light of the model insulator the difficulty largely disappears. No matter what the absorbent material may be, the same fundamental conditions are always present: the positively charged water, the potential gradient, surface tension, and fluid friction. I feel that if these quantities could all be equated we could construct a rational formula to the moisture curve.

Mr. Peck asked how much time was occupied over the readings. If the insulator was fairly stable, and the capacity current negligible compared with the leakage current, the galvanometer could be read at once. With unstable insulators it is generally advisable to wait a few minutes before observing the current, and where the capacity current is comparatively large it is essential to wait—sometimes for half an hour or more. But even with an insulator as sluggish as the model is in coming to a steady state, quite a good curve may be obtained by taking the readings as quickly as possible, and although the resistance values are considerably higher in consequence, yet the curve has the normal shape. For example, in Fig. 31, curve B was plotted from readings which I took at the Institution as rapidly as the ohmmeter would permit.

I cannot agree with Mr. Cramp that the vapour in the air bubble would have any sensible conductivity at the low potential gradients which generally prevail throughout the greater part of the moisture curve, but of course as the voltage rises there must come a time when the current through the vapour can no longer be neglected.

Mr. Cunliffe's experiment with the moist sand is a good example of the action of endosmose in driving the water away from the positive electrode. With alternating current I think the water should leave both electrodes and collect somewhere in between them. I have not noticed any rise of resistance consequent on a prolonged application of pressure during the tests given in the paper, although I have been on the look-out for it. Probably the test-pieces always held a sufficient quantity of dormant water to supply the stream through the film for a long time, but the point is at present rather obscure.

Mr. Crellin refers, as Mr. Bairsto had already done, to Appleyard's experiments on the contact between an insulator and the electrodes. Of course I accept the facts, but none of the hypotheses which have been put forward by way of explanation carry conviction to my mind. For one thing, the way in which the moisture curve retains its normal curvature throughout a wide range of moisture condition is quite inconsistent with any kind of effect at the terminals. Mr. Appleyard took a thin sheet of press-pahn and, with solid electrodes making light contact, he traced the voltage-resistance curve. This curve is a typical moisture curve, the ratio R_{7}/R_{107} being about 2·6, and the hysteresis effect is well marked. Finding, as I have since done (see Fig. 16), that pressing the electrodes into firmer contact with the insulator greatly reduced the curvature, Mr. Appleyard next tried the far more perfect contact made by fluid mercury electrodes, and discovered that the resistance of the press-pahn no longer varied with the potential difference. This remarkable experiment not unnaturally suggested that the voltage-resistance curve was the result of something going on at the electrodes, some kind of contact effect; but I am going to suggest another explanation which tallies better with the facts as we now know them. To obtain any flow, any motion, in the moisture films, it is, I believe, essential that the capillary channels should have free access to the air at both ends, a condition which is of course perfectly fulfilled by the little tubes in the model. Plug the tubes, stop the ends of the capillary channels in an absorbent insulator, and I think it would no longer be possible to obtain any motion by the action of endosmose. But if the water cannot flow the films cannot increase their thickness, and hence we should expect the resistance of a plugged channel to remain constant notwithstanding changes in potential difference. Now as we press the electrodes more and more firmly into contact with the porous insulator, we may be simply stopping up the pores one after another, and by means of his mercury electrodes Mr. Appleyard may have plugged the whole of them. Of course this is but a guess; I have not had time to test it by experiment. But if I am right, then we should expect mercury electrodes to have the greatest effect, in stopping the action of endosmose, when they are applied to a thin sheet of insulating material; and to have less and less effect as the insulator was made thicker and air was able to find its way in through the edges or sides of the porous body.

Mr. Atkinson has made a most interesting and helpful contribution to the discussion. In the unavoidable process of compressing my paper into a reasonable length I rather reluctantly cut out a description of the mode in which moisture is deposited in a thin and invisible film which, as it thickens, collects into visible drops. But I am rewarded for my self-denial because Mr. Atkinson has now described what goes on much more fully than I had done and with far more knowledge than I possess.

By the way, I recall that it was in 1888 that my attention was first directed to the subject of insulation testing by Mr. Atkinson and the late Mr. Walter Goolden. They suggested that I should devise something by way of improvement on the portable battery and galvanometer which was in general use at that time. Twenty-five years have gone by, and I am still looking for an improved method.

THE MAGNETIC LEAKAGE OF SALIENT POLES.

By ROBERT POHL, D.Eng., Member.

(*Paper received 22nd October, 1913.*)

In the course of an investigation of the regulation of alternators the author found that none of the usual methods of calculating regulation gave consistently reliable results in practice when applied to a range of machines and to various working conditions, and that the discrepancies were largely due to the variability of the leakage factor. The leakage flux is not constant, but increases with increasing load, especially if the latter is inductive, and thus causes an appreciable difference between the flux characteristic at no load and at full load. This subject will be more fully dealt with in a separate publication.

These results led the author to the conclusion that it is necessary to calculate the leakage both at no load and at full load separately, and much more accurately than he had been accustomed to. It was found, however, on looking through text-books and publications dealing with the predetermination of the leakage factor, that there is need for a fuller mathematical investigation of the problem with a view to obtaining some formulæ for practical use in designing offices. Such formulæ, in order to be of real utility, should be as simple as possible. At the same time, however, they must give accurate results. These two conditions, considering the complicated character of the leakage paths and the variety of shapes of poles and exciting coils used in practice, are not easily reconciled.

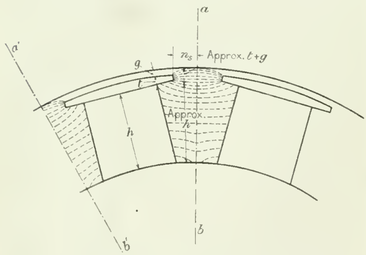

FIG. 1.

The following is an attempt to supply a fairly comprehensive mathematical investigation leading up to formulæ for practical designing work. The formulæ, though surprisingly simple, are obtained without any undue compromise, and will be shown to bear the test of experimental verification. Indeed, the writer has employed them with entirely satisfactory results for a variety of electrical machines. Needless to say these calculations do not require to be worked out for every machine passing through a manufacturer's works, but only for new designs. The general method of treatment, being based on well-known first principles, cannot, of course, be claimed to be novel.

As the basis for our investigation let us consider the design of poles usual in the revolving-field type of alternators. The formulæ obtained will be immediately applicable to other classes of salient-pole machines, more particularly continuous-current machines. Fig. 1 represents a diagrammatic view of the flux distribution of such poles. In accordance with the usual definition we shall call the leakage factor σ the ratio of the total flux F_t passing through the base of the pole to the useful flux F_u entering the stator iron and interlinking with the stator winding. F_u may be considered a known quantity. The leakage flux L is the difference between the total flux and the useful flux.

$$\sigma = \frac{F_t}{F_u} = \frac{F_u + L}{F_u} = 1 + \frac{L}{F_u}.$$

The unknown quantity L may be divided into two main parts, the shoe leakage L_s and the core leakage L_c. Each

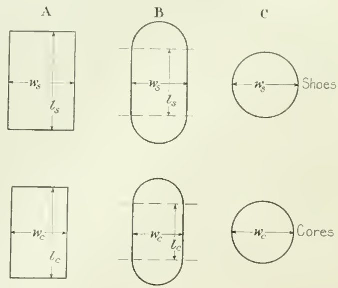

FIG. 2.

of these may again be divided into two sections, the first, hereinafter called "face leakage," comprising the lines that pass between those parts of the shoes and the cores respectively which directly face each other; the second those which emerge from the ends.

Let L_{s1} = face leakage of shoe,
L_{s2} = end leakage of shoe,
L_{c1} = face leakage of core,
L_{c2} = end leakage of core.

In addition to the above sub-division we shall have to consider various forms of pole-cores and shoes as used in practice. These are illustrated in Fig. 2, and will be referred to as follows:—

A Rectangular type.
B Rectangular type with semi-circular ends.
C Circular type.

We have to calculate the leakage for types A and B; that of type C is then obtained from B by omitting the face leakage. It is not unusual, of course, to have circular pole-cores with rectangular shoes, or cores of type B with rectangular shoes, and in this case the equation for the shoe of type A will have to be employed in conjunction with formulæ for the core of type B or C.

Finally, two different forms of exciting coils will have to be considered, namely, the non-stepped or parallel coil and the stepped coil. In the former the number of ampere-turns per unit of length is constant and the coil is of uniform thickness. In the latter, with the object of the better utilization of the available space, the thickness increases, generally towards the shoe, and so does the number of ampere-turns per unit of length. It will be seen that for a given magnetomotive force the shape of the coil, *i.e.* the distribution of its ampere-turns, does not affect the shoe leakage but only the core leakage.

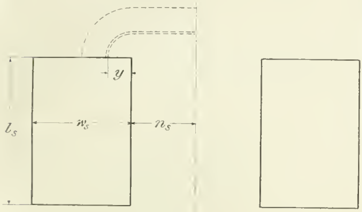

FIG. 3.

Our procedure is therefore as follows :—

Shoe leakage.
Calculations of L_{s1} and L_{s2} for
type A;
type B;
type C.

Core leakage.
(1) Non-stepped coils.
Calculation of L_{c1} and L_{c2} for
type A;
type B;
type C.
(2) Stepped coil.
Calculation of L_{c1} and L_{c2} for
type A;
type B;
type C.

Referring to Fig. 1 the lines $a\,b$ and $a'\,b'$ represent planes through the centre of the neutral zone and the shaft. It will be seen that these are equipotential planes of the magnetic system, and hence all lines of force have to pass through them at right angles. The magnetomotive force of the pole drives the flux to these planes, whence it is carried into the adjacent poles under the influence of the magnetomotive force of the latter. We may therefore consider the section of the magnetic system between the planes $a\,b$ and $a\,b$ as an independent unit for all future calculations.

SHOE LEAKAGE.

A. *Rectangular type.*—The leakage flux emerging from the two straight parts of length l_s (Fig. 3) is—

$$L_{s1} = M\,M\,F_s\,(t+g)\,\frac{2\,l}{n_s} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where the average depth of the path is taken as $(t+g)$ and its average length as n_s (see Fig. 1), whilst M M F_s denotes the magnetomotive force producing the shoe leakage. How to express M M F_s in terms of ampere-turns will be discussed later.

The leakage from the two straight ends is also easily obtained. We assume that the paths followed by all lines are parts of a circle of radius y followed by a straight part of length n_s. This is not strictly correct, since theoretically

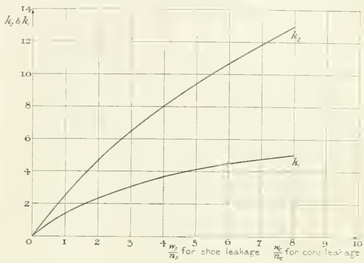

FIG. 4.

the lines must spread out to an infinite distance; but the error thus introduced can only be small. We further make the assumption, not strictly correct, that the depth of the path is $(t+g)$ and obtain

$$L_{s2} = M\,M\,F_s\,(t+g) + \int_{y=0}^{y=\frac{\omega_s}{2}} \frac{dy}{n_s + y\,\pi/2}$$

where ω_s = the width of the shoe (circumferentially).

The integral is easily calculated * and leads to—

$$L_{s2} = M\,M\,F_s\,(t+g)\;5{\cdot}85\,\log\left(1 + \frac{\pi}{4}\,\frac{\omega_s}{n_s}\right) \quad . \quad . \quad (2)$$

It will be observed that for given values of M M F and $(t+g)$, L_{s2} does not depend on the size of the shoe but only on the ratio ω_s/n_s, or, in other words, on the ratio (pole arc)/(pole pitch). We may therefore simplify Equation 2 by writing—

$$L_{s2} = M\,M\,F_s\,(t+g)\,k_1 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where k_1 is a constant for all machines having the same

* See Appendix, I.

ratio of pole arc to pole pitch. The value of k_1, namely, $5{\cdot}85 \log\left(1 + \frac{\pi}{4}\frac{\omega_s}{n_s}\right)$, is plotted in Fig. 4 as a function of ω_s/n_s.

Combining Equations 1 and 3—

Leakage of a rectangular shoe=

$$\text{M M F}_s\,(l+g)\left(\frac{2\,l_s}{n_s} + k_1\right) \quad . \quad (4)$$

B. *Rectangular type with semicircular ends.*—The face leakage remains obviously the same as in the previous case (see Equation 1). The end leakage, however, is considerably altered by the semicircular form. The leakage from a semicircle (Fig. 5) does not at first sight lend itself to a simple treatment. The curved lines of force will again pass at right angles through the equipotential plane $a\,b$ and will emerge at right angles from the surface of the shoe. To meet these conditions and closely to approach the real

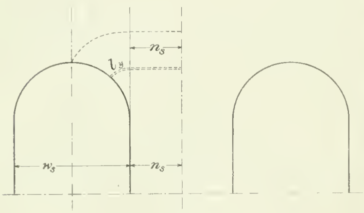

FIG. 5.

distribution let us assume that every line is composed as before of a straight part of length n_s and of part of an involute, as is shown in Fig. 5. This assumption renders the mathematical treatment comparatively easy and furnishes an exceedingly simple solution of the problem. If l_y be the length of the tube of force shown in Fig. 5 we have—

$$\text{L}_{s2} = \text{M M F}_s\,(l+g)\,4\int_{y=0}^{y=\frac{\omega_s\pi}{4}} \frac{dy}{l_y}.$$

Now l_y consists of n_s and the arc of an involute, and we obtain*—

$$\text{L}_{s2} = \text{M M F}_s\,(l+g)\,4\sqrt{\frac{\omega_s}{n_s}}\tan^{-1}\left(\frac{\pi}{4}\sqrt{\frac{\omega_s}{n_s}}\right) \quad . \quad (5)$$

It is interesting again to observe that the leakage flux for given values of M M F_s and $(l+g)$ depends only on the ratio ω_s/n_s, and hence on the ratio (pole arc)/(pole pitch); and it is thus a constant quantity, irrespective of the size of the pole, provided ω_s/n_s remains the same. One might conclude from this that the leakage factor σ of a series of machines of similar design would rapidly decrease as the size of frame increases. This is not the case, however, simply because $(l+g)$ and M M F_s increase as the size of frame increases; hence the ratio of the leakage flux to the useful flux does not decrease appreciably. The dependence on the ratio ω_s/n_s, however, enables us again to simplify Equation 5 for practical use by writing it—

* See Appendix, II.

Leakage of semicircular ends $= \text{M M F}_s\,(l+g)\,k_2 \quad . \quad . \quad (6)$

where $k_2 = 4\sqrt{\frac{\omega_s}{n}}\tan^{-1}\left(\frac{\pi}{4}\sqrt{\frac{\omega_s}{n_s}}\right)$, which is a constant, to be taken from a curve having values of the ratio ω_s/n_s as abscissæ. Such a curve for k_2 is given in Fig. 4.

Combining Equations (1) and (6) we find—

Leakage of rectangular shoe with semicircular ends=

$$\text{M M F}_s\,(l+g)\left(\frac{2\,l_s}{n_s} + k_2\right) \quad . \quad (7)$$

C. *Circular type.*—The leakage from a circular shoe is equal to the end leakage of the previous example, stated in Equation 6, which may thus be repeated—

Leakage of circular shoe $= \text{M M F}_s\,(l+g)\,k_2 \quad . \quad (6)$

CORE LEAKAGE.

The chief difference between the core and the shoe with regard to leakage consists in a difference in the magneto-

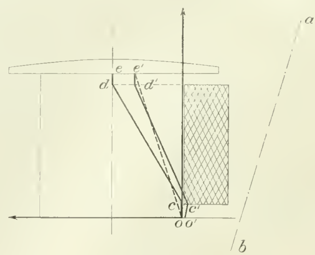

FIG. 6.

motive force producing it. Whilst the magnetic potential of the shoe, M M F_s, is the same for all points on its surface, that of the core, commencing at the root and ascending to the shoe, rises from zero, or to be more accurate from a small negative value, to M M F_s, and the rate at which it increases depends on the shape of the exciting coils and the magnetomotive force absorbed in the pole itself.

1. NON-STEPPED COILS.

Fig. 6 depicts a pole with a coil of uniform thickness (non-stepped coil), $a\,b$ represents the equipotential plane midway between two poles, which we take as our zero of magnetic potential. We may then plot the magnetic potential or magnetomotive force producing the leakage flux along the core. This would be represented by the line $o\,c\,d\,e$ if there were no drop of potential in the pole and yoke. Taking this drop into consideration, however, the magnetomotive force is represented by the line $o'c'd'e'$, which at the root of the pole gives a small negative value $o\,o'$

equivalent to the magnetomotive force absorbed in the yoke, and rises to its maximum at d', this maximum being $M M F_s$, where—

$$M M F_s = \frac{4\pi}{10}\left(\begin{array}{l}\text{total ampere turns} \\ \quad - \text{ampere turns of pole and yoke}\end{array}\right) \quad . \quad (8)$$

Without committing a serious mistake we may replace the broken line $o'c\,d'e'$ by the straight line $o\,e'$ as long as we are dealing with non-stepped coils, and thus find with reference to Fig. 7—

$$M M F_x = M M F_s \frac{x}{h} \quad . \quad . \quad . \quad . \quad (9)$$

A. *Rectangular type.*—Again referring to Fig. 7 and the

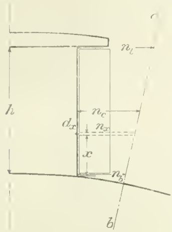

FIG. 7.

notation there indicated we can now calculate the leakage flux L_{c1} passing between the straight faces of length l_c—

$$L_{c1} = \int_{x=0}^{x=h} M M F_x \frac{2\,l_c\,d\,x}{n_x}, \text{ where } n_x = n_b + (n_t - n_b)\,x/h,$$

hence $$L_{c1} = M M F_s \frac{2\,l_c}{h} \int_{x=0}^{x=h} \frac{x\,d\,x}{n_b + (n_t - n_b)\,x/h},$$

which gives *—

Core leakage of straight faces (non-stepped coils) =

$$L_{c1} = \frac{M M F_s}{2} h \frac{2\,l_c}{n_c} \left[\frac{\partial + 1}{\partial - 1}\left(1 - \frac{\log_e \partial}{\partial - 1}\right)\right] \quad . \quad (10)$$

where $\partial = \frac{n_t}{n_b}$, and $n_c = \frac{n_t + n_b}{2}$.

We may simplify Equation 10 by writing it—

$$L_{c1} = \frac{M M F_s}{2} h \frac{2\,l_c}{n_c} f_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where $f_1 = \frac{\partial + 1}{\partial - 1}\left(1 - \frac{\log_e \partial}{\partial - 1}\right)$ and depends only on $\partial = n_t/n_b$; it may therefore be plotted once and for all as a function of n_t/n_b. This is done in Fig. 8.

The similarity between Equation 11 and Equation 1 is now apparent. The only important difference in its constitution consists in the additional factor f_1, which takes into consideration the effect on the leakage of the angle between the poles, and becomes equal to unity when the poles are parallel, *i.e.* for $n_t = n_b$.

* See Appendix, III.

It requires no elaborate calculation to realize that the leakage from the two ends of the pole may be expressed by an equation corresponding to Equation 3, but again containing the same correction factor f_1.

Core leakage of rectangular ends (non-stepped coil) =

$$L_{c2} = \frac{M M F_s}{2} h\,k_1 f_1 \quad . \quad (12)$$

where $k_1 = 5{\cdot}85 \log\left(1 + \frac{\pi}{4}\frac{\omega_c}{n_c}\right)$, and may be taken from Fig. 4, so that the total core leakage becomes—

$$L_c = L_{c1} + L_{c2} = \frac{M M F_s}{2} h \left(\frac{2\,l_c}{n_c} + k_1\right) f_1 \quad . \quad . \quad (13)$$

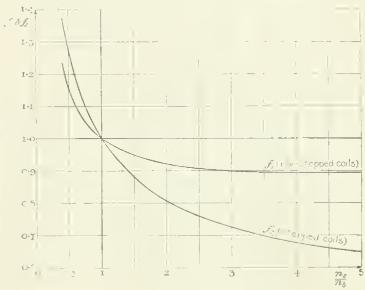

FIG 8.

In the same manner we find for the—

B. *Rectangular type with semicircular ends.*

$$\text{Core leakage} = L_c = \frac{M M F_s}{2} h \left(\frac{2\,l_c}{n_c} + k_2\right) f_1 \quad . \quad (14)$$

where $k_2 = 4\sqrt{\frac{\omega_c}{n_c}} \tan^{-1}\left(\frac{\pi}{4}\sqrt{\frac{\omega_c}{n_c}}\right)$ and is plotted in Fig. 4.

C. *Circular type.*

Core leakage of circular pole (non-stepped coil) =

$$L_c = \frac{M M F_s}{2} h\,k_2\,f_1 \quad . \quad (15)$$

2. STEPPED COILS.

The equations for the core leakage so far obtained are all based on the assumption that we are dealing with coils having a uniform number of ampere-turns per unit of length, so that the equation $M M F_x = M M F_s\,x/h$ is sufficiently accurate for our purposes (Figs. 6 and 7). This ceases to be the case, however, as soon as we adopt stepped coils as shown in Fig. 9. Contemplating the extreme case depicted in Fig. 9, where the whole space

available between the poles is occupied by the field winding, it will be seen that $M\,M\,F_x$, *i.e.* the magnetomotive force acting on the strip of length n_x and depth dx, is proportional to the sectional area of the coil below n_x, and may be expressed by

$$M\,M\,F_x = M\,M\,F_s \frac{(n_x + n_b)\,x}{(n_t + n_b)\,h} = M\,M\,F_s \frac{n_x + n_b}{2\,n_c} \cdot \frac{x}{h} \quad . \quad (16)$$

It may be noted that the following equations for stepped coils will hold good, although the winding space may not be completely filled up as assumed in Fig. 9, provided only that the distribution of ampere-turns over the coil approximates to that expressed by Equation 16.

A. *Rectangular type.*

Face leakage =

$$L_{c1} \int_{x=0}^{x=h} M\,M\,F_x \frac{2\,l_c\,dx}{n_x} = \frac{M\,M\,F}{2\,h} \frac{2\,l_c}{n_c} \int_{x=0}^{x=h} (n_x + n_b) \frac{x\,dx}{n_x}$$

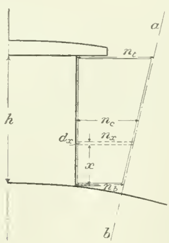

FIG. 9.

The solution of this equation is *—

$$L_{c1} = \frac{M\,M\,F_s}{2} h \frac{2\,l_c}{n_c} \left[\frac{1}{2} + \frac{1}{\partial - 1} - \frac{\log_e \partial}{(\partial - 1)^2}\right] \quad . \quad (17)$$

where again $\partial = n_t / n_b$. L_{c1} may be more simply obtained by plotting $\left[\frac{1}{2} + \frac{1}{\partial - 1} - \frac{\log_e \partial}{(\partial - 1)^2}\right] = f_2$ once and for all as a function of ∂ (see Fig. 8). Then the

Core leakage of straight faces (stepped coil) =

$$L_{c1} = \frac{M\,M\,F_s}{2} h \frac{2\,l_c}{n_c} f_2 \quad . \quad (18)$$

This formula is identical with the corresponding one for non-stepped coils (Equation 11), the only difference being that f_2 has taken the place of f_1. This is bound to apply equally to Equations 12, 13, 14, and 15, which will change into—

Core leakage of rectangular ends (stepped coil) =

$$L_{c2} = \frac{M\,M\,F_s}{2} h\,k_1\,f_2 \quad . \quad (19)$$

* See Appendix, IV.

Core leakage of rectangular pole (stepped coil) =

$$L_c = L_{c1} + L_{c2} = \frac{M\,M\,F_s}{2} h \left(\frac{2\,l_c}{n_c} + k_1\right) f_2 \quad . \quad (20)$$

B. *Rectangular type with semicircular ends.*

Core leakage of rectangular pole with semicircular ends (stepped coil) =

$$L_c = \frac{M\,M\,F_s}{2} h \left(\frac{2\,l}{n_c} + k_2\right) f_2 \quad . \quad (21)$$

C. *Circular type.*

Core leakage of circular pole (stepped coil) =

$$L_c = \frac{M\,M\,F_s}{2} h\,k_2\,f_2 \quad . \quad (22)$$

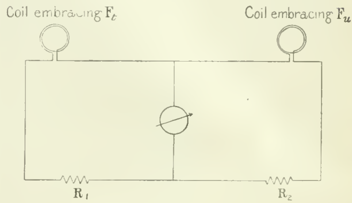

FIG. 10.

Where the stepping of the coils is distinctly less pronounced than that assumed in Equation 16 a factor f will have to be suitably chosen for Equations 20, 21, and 22, intermediate between f_1 and f_2 in Fig. 8.

It may here be noted that the curves in Fig. 8 have been worked out for $n_t/n_b < 1$, *i.e.* external poles, as well as for

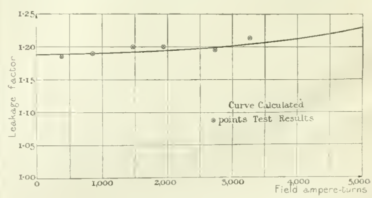

FIG. 11.—Variation of Leakage Factor with Excitation on no Load.

$n_t/n_b > 1$, *i.e.* internal poles. In the former case the leakage is increased by stepping the coils ($f_2 > f_1$), whilst in the latter case it is reduced ($f_2 < f_1$).

It would, of course, be an easy matter to obtain formulæ for the total leakage of the various types by combining and further simplifying the respective equations for the shoe and core leakage, but it appears preferable to the writer to work these out separately, because by so doing the various sources of leakage are better kept under observation, and where the leakage factor is found to be too high

the cause is more readily recognized and the remedy applied.

Experimental Verification.

In order to test the accuracy of the foregoing formulæ the leakage of a 460-k.v.a. Phœnix alternator was calculated for a number of points along its no-load characteristic. The leakage factor σ thus obtained by calculation was then checked on the actual machine by applying a simple test, previously described by the author,* the principle of which is briefly as follows :—

Two coils containing an equal number of turns of wire are placed on the machine, one round the root of the pole so as to embrace the total flux F_t, the other against the armature or stator so as to embrace the useful flux F_u only. The coils are connected in series across two resistances of a Post Office box, Wheatstone bridge fashion, with an ordinary millivoltmeter connected to the junctions, as shown in Fig. 10. The resistances are then adjusted so that on breaking or making the field of the machine no deflection is obtained. We then find the leakage factor $\sigma = F_t/F_u = R_1/R_2$.

The leakage factor is immediately given by dividing R_1 by 100, if we keep R_2 constant at 100 ohms and adjust R_1 only until the desired result is obtained. The curve in Fig. 11 represents the calculated values of σ as a function of the excitation, the points being the test results, and it will be seen that the agreement is very satisfactory.

In place of a summary a table may here be reproduced (Fig. 12) which has been prepared to expedite routine calculations of the leakage factor in ordinary design work. The formulæ for the shoe leakage of types B and C have been omitted from this table, as such shoes occur so very rarely in practice.

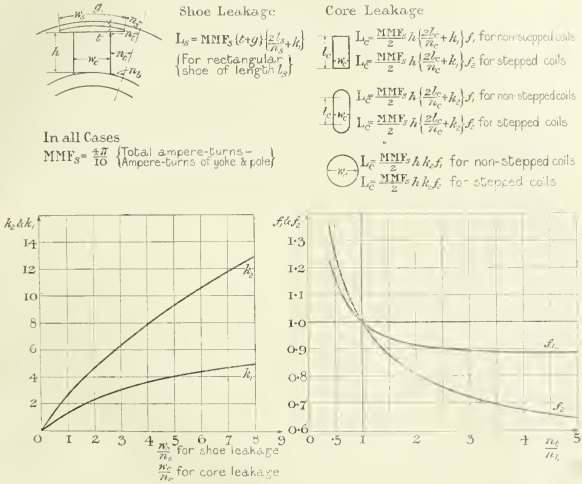

FIG. 12.

* *Electrician*, vol. 59, p. 215, 1907.

Appendix.

I. *Derivation of Equation 2 and of the factor k_1, plotted in Fig. 4.*

$$L_{s2} = M\,M\,F_s\,(t+g)\,4\int_{y=0}^{y=\frac{w_s}{2}} \frac{dy}{n_s + y\,\pi/2}$$

$$\int_{y=0}^{y=\frac{w_s}{2}} \frac{dy}{n_s + y\,\pi/2} = \frac{2}{\pi}\left[\log_e\left(n_s + \frac{y\,\pi}{2}\right)\right]_{y=0}^{y=\frac{w_s}{2}}$$

$$= \frac{2}{\pi}\left[\log_e\left(n_s + \frac{w_s\,\pi}{4}\right) - \log_e n_s\right] = \frac{4\cdot6}{\pi}\log\left(1 + \frac{\pi}{4}\frac{w_s}{n_s}\right)$$

$$L_{s2} = M\,M\,F_s\,(t+g)\,5\cdot85\log\left(1+\frac{\pi}{4}\frac{w_s}{n_s}\right) = M\,M\,F_s\,(t+g)\,k_1$$

$$k_1 = 5\cdot85\log\left(1+\frac{\pi}{4}\frac{w_s}{n_s}\right).$$

II. *Derivation of Equation 5 and of the factor k_2, plotted in Fig. 4.*

$$L_{s_2} = M\,M\,F_s\,(l+g)\,4\int_{y=0}^{y=\omega_s\frac{\pi}{4}} \frac{d\,y}{l_y}$$

where $l_y = n_s + \text{arc of involute} = n_s + \frac{\omega_s}{2}\frac{\alpha^2}{2} = n_s + y^2/\omega_s$,

since $\alpha = \frac{y}{\omega_s/2}$.

Putting $y^2\,\omega_s = x^2$, whence $x = y/\sqrt{\omega_s}$ and $d\,y = \sqrt{\omega_s}\,d\,x$ also $n_s = a^2$, whence $a = \sqrt{n_s}$, we find—

$$\int \frac{d\,y}{n_s + y^2/\omega_s} = \sqrt{\omega_s}\int\frac{d\,x}{a^2 + x^2}.$$

Now
$$\int\frac{d\,x}{a^2+x^2} = \frac{1}{a}\tan^{-1}\frac{x}{a}$$

hence—

$$\int_{y=0}^{y=\omega_s\frac{\pi}{4}} \frac{d\,y}{n_s + y^2/\omega_s} = \sqrt{\frac{\omega_s}{n_s}}\left[\tan^{-1}\frac{y}{\sqrt{\omega_s\,n_s}}\right]_{y=0}^{y=\omega_s\frac{\pi}{4}}$$

$$= \sqrt{\frac{\omega_s}{n_s}}\tan^{-1}\left(\frac{\pi}{4}\sqrt{\frac{\omega_s}{n_s}}\right)$$

$$L_{s_2} = M\,M\,F_s\,(l+g)\,4\sqrt{\frac{\omega_s}{n_s}}\tan^{-1}\left(\frac{\pi}{4}\sqrt{\frac{\omega_s}{n_s}}\right)$$
$$= M\,M\,F_s\,(l+g)\,k_2$$

$$k_2 = 4\sqrt{\frac{\omega_s}{n_s}}\tan^{-1}\left(\frac{\pi}{4}\sqrt{\frac{\omega_s}{n_s}}\right).$$

III. *Derivation of Equation 11 and of the factor f_1 plotted in Fig. 8.*

$$L_{c1} = M\,M\,F_s\,\frac{2\,l_c}{h}\int_{x=0}^{x=h}\frac{x\,d\,x}{n_b + (n_t - n_b)\,x/h}.$$

Substituting $n_b + (n_t - n_b)\frac{x}{h} = t$, and $x = \frac{(t-n_b)\,h}{n_t - n_b}$,

whence $d\,x = \frac{h}{n_t - n_b}\,.\,d\,t$

$$\int_{x=0}^{x=h}\frac{x\,d\,x}{t} = \int_{t=n_b}^{t=n_t}\frac{h^2}{(n_t-n_b)^2}\cdot\frac{t-n_b}{t}\cdot d\,t = \frac{h^2}{(n_t-n_b)^2}\Big[t - n_b\log_e t\Big]_{t=n_b}^{t=n_t}$$

$$= \frac{h^2}{(n_t-n_b)^2}\left[n_t - n_b - n_b\log_e\frac{n_t}{n_b}\right].$$

Now, putting $\frac{n_t}{n_b} = \partial$, $n_t = \partial\,n_b$, $n_t - n_b = n_b(\partial - 1)$

$$\int_{x=0}^{x=h}\frac{x\,d\,x}{t} = \frac{h^2}{n_b^2(\partial-1)^2}\left[n_b(\partial-1) - n_b\log_e\partial\right]$$

$$= \frac{h^2}{n_b(\partial-1)}\left(1 - \frac{\log_e\partial}{\partial-1}\right) = \frac{h^2}{n_b(\partial+1)}\cdot\frac{\partial+1}{\partial-1}\left(1-\frac{\log_e\partial}{\partial-1}\right)$$

$$= \frac{h^2}{2\,n_c}\frac{\partial+1}{\partial-1}\left(1-\frac{\log_e\partial}{\partial-1}\right)$$

since $n_b(\partial+1) = n_t + n_b = 2\,n_c$. Hence—

$$L_{c1} = \frac{M\,M\,F_s}{2}\,h\,\frac{2\,l_c}{n_c}\left[\frac{\partial+1}{\partial-1}\left(1-\frac{\log_e\partial}{\partial-1}\right)\right] = \frac{M\,M\,F_s}{2}\,h\,\frac{2\,l_c}{n_c}\,f_1$$

$$f_1 = \frac{\partial+1}{\partial-1}\left(1-\frac{\log_e\partial}{\partial-1}\right) \qquad \partial = \frac{n_t}{n_b}.$$

IV. *Derivation of Equation 17 and of the factor f_2, plotted in Fig. 8.*

$$L_{c1} = \int_{x=0}^{x=h} M\,M\,F_x\,\frac{2\,l_c\,d\,x}{n_x} = \frac{M\,M\,F_s}{2\,n_c\,h}\,2\,l_c\int_{x=0}^{x=h}(n_x+n_b)\frac{x\,d\,x}{n_x},$$

where $n_x = n_b + (n_t - n_b)\frac{x}{h}$.

$$\int_{x=0}^{x=h}(n_x+n_b)\frac{x\,d\,x}{n_x} = \int_{x=0}^{x=h}x\,d\,x + n_b\int_{x=0}^{x=h}\frac{x\,d\,x}{n_b + (n_t-n_b)\,x/h}.$$

The solution of the former integral is $h^2/2$; that of the latter has been found under III, and is—

$$\frac{h^2}{2\,n_c}\frac{\partial+1}{\partial-1}\left(1-\frac{\log_e\partial}{(\partial-1)}\right)$$

hence—

$$\int_{x=0}^{x=h}(n_x+n_b)\frac{x\,d\,x}{n_x} = \frac{h^2}{2} + \frac{h^2\,n_b}{2\,n_c}\cdot\frac{\partial+1}{\partial-1}\left(1-\frac{\log_e\partial}{\partial-1}\right).$$

Now $n_b(\partial+1) = n_t + n_b = 2\,n_c$, therefore—

$$\int_{x=0}^{x=h}(n_x+n_b)\frac{x\,d\,x}{n_x} = h^2\left[\frac{1}{2} + \frac{1}{\partial-1}\left(1-\frac{\log_e\partial}{\partial-1}\right)\right]$$

$$= h^2\left[\frac{1}{2} + \frac{1}{\partial-1} - \frac{\log_e\partial}{(\partial-1)^2}\right]$$

$$L_{c1} = \frac{M\,M\,F_s}{2}\,h\,\frac{2\,l_c}{n_c}\left[\frac{1}{2} + \frac{1}{\partial-1} - \frac{\log_e\partial}{(\partial-1)^2}\right]$$
$$= \frac{M\,M\,F_s}{2}\,h\,\frac{2\,l_c}{n_c}\,f_2$$

$$f_2 = \frac{1}{2} + \frac{1}{\partial-1} - \frac{\log_e\partial}{(\partial-1)^2}.$$

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BRITISH PRACTICE IN THE CONSTRUCTION OF HIGH-TENSION OVERHEAD TRANSMISSION LINES.

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In our large industrial centres, where electrical energy is usually conveyed to consumers by underground cables, it is frequently not realized what extensive use of overhead wires is being made in country districts for the same purpose. So far as can be ascertained there are already nearly 1,000 miles of overhead lines in the United Kingdom which are operated at alternating pressures between 2,000 and 20,000 volts inclusive; and of these there are 115 miles in operation or under construction for 20,000-volt working. The author thinks that the time has arrived when it will be of use to engineers and others to have some account of the construction of lines as developed to meet British conditions only, with a view to a helpful discussion of the various problems which are still unsolved. We have no transmission lines over long distances and at high voltages in the sense in which they are understood in other parts of the world. Such lines were designed to meet very different conditions from those obtaining in this country, and they have recently * been fully described before this Institution.

It is not within the scope of this paper to examine the problem of the distance to which it is commercially economical to transmit electricity in preference to carrying fuel, but it may be recorded that our longest direct transmission line is only about 20 miles in length, while one of 40 miles is under consideration.

It may be taken for granted that pole lines have come to stay in rural districts, where low first cost is of paramount importance in enabling supply authorities to give a cheap supply of energy to industrial works, collieries, houses, etc. It is not necessary to state the case for overhead lines at any length, but it may be well to give the following figures for 3-phase transmission to illustrate the saving in first cost between underground cables and overhead lines. In compiling these figures of costs per mile, care has been taken to include everything required for work of the highest

* W. T. TAYLOR. Modern Long-distance Transmission of Electrical Energy. *Journal I.E.E.*, vol. 46, p. 510, 1911.
R. B. MATTHEWS and C. T. WILKINSON. Extra-high-pressure Transmission Lines. *Journal I.E.E.*, vol. 46, p. 562, 1911.
A. E. HADLEY. Power Supply on the Rand. *Journal I.E.E.*, vol. 51, p. 2, 1913.

class. Copper has been taken at £60 per ton, and lead at £20 per ton. The copper conductors comprise three of 0·10 sq. in. section in each case. No buildings, transformers, or switchgear are included, and it should be borne in mind that the annual maintenance and depreciation charges on an overhead line are necessarily heavier than on a modern cable system.

Voltage	Cable Laid and Jointed, including Street Work	Overhead Line of equal Kilowatt Capacity
	£	£
6,000	1,400	900
11,000	1,550	950
20,000	2,100	950

1. The Postmaster-General possesses powers for erecting telegraph and telephone lines, but the procedure to be followed is so cumbersome as to be almost useless. Even these powers are denied to electric supply authorities.

2. Under the Electric Lighting Acts the consent of the local authority must be obtained by a statutory undertaker previous to the erection of overhead wires, whether these are in the public street or on private land.

3. Non-statutory undertakers can dispense with the consent of the local authority and both erect wires on private land and cross public roads so long as the wires cause no obstruction above the roadway.

4. Non-statutory undertakers may erect overhead lines without compliance with the Board of Trade regulations, but the Board has power, if it thinks fit, to order such compliance.

The author thinks that a strong case has been made out to justify the Council of this Institution in making representations to the Board of Trade for the benefit of the electrical industry and all consumers with a view to removing the inconsistencies which exist in the law. At the same time, efforts should be made to secure :—

1. A curtailment of the absolute veto on the construction of overhead wires by a local authority.

2. The local authority's refusal of consent should be made subject to an appeal to the Board of Trade. At present such an appeal is only allowed to power companies' wires in *rural* districts. The author would further suggest that this one subject should be taken up by itself and that success should not be endangered by making representations on other matters at the same time.

All high-tension lines should be designed to comply with the current regulations of the Board of Trade, or with approved modifications, and it cannot be too strongly emphasized that the success or otherwise of all lines will be very largely dependent on the close attention which is paid both to the design and to the erection of every detail.

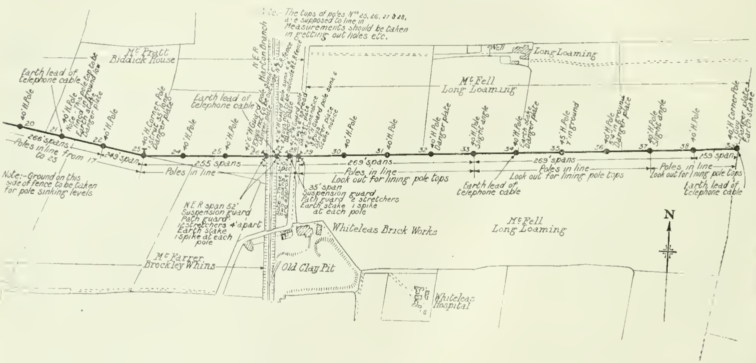

Fig. 1.—Route Map.

Incidentally, this Table shows how little influence the working pressure has on the first cost of an overhead line in this country.

Through this cheapened means of transmission much electrification work is now being undertaken which would otherwise not be commercially possible. The extensive use of overhead lines has thus become of enormous benefit to the manufacturers of electrical plant, cables, and accessories, as well as to the supply authorities and their consumers.

The principal difficulty in pole-line work across country is that arising from the necessity of negotiating wayleaves, and these negotiations are frequently very prolonged. This subject has been fully discussed by Mr. C. Vernier in his Address* (October, 1913) to the Newcastle Local Section of this Institution, and that part of the Address which deals with the inconsistent state of the law on the question of wayleaves, etc., may be summarized as follows :—

* *Journal I.E.E.*, vol. 52, No. 223, p. 17.

For instance, to secure the best results, it is essential that the engineers should survey and set out the line and then prepare and issue to the constructional engineers a route plan giving all essential details of what is required. Fig. 1 gives a copy of such an actual plan which is a model of lucidity. In the author's opinion it is not conducive to the best results or to economical erection for the setting out of the work to be left to the construction engineer to do at the last moment. Another essential is that the clerk of works should be competent and not be hampered by inelastic instructions. In making the survey of the line a useful instrument is Captain Abney's clinometer level fitted with a compass.

Factors of Safety.

Considerable criticism was directed some time ago against the requirements of the Board of Trade that the conductors should have a factor of safety of 5 at 22° Fahr. and wooden poles a factor of safety of 10, in both cases taking the wind pressure at 30 lb. per square foot of the exposed effective areas, whereas another Government Department—the General Post Office—only used factors of 4 and 8 respectively and took the maximum wind pressure at 17 lb. per square foot. In both cases accumulations of ice or snow are not taken into account. The Board of Trade has recently made an alteration in its requirements by reducing the wind pressure figure to 25 lb. per square foot, and Revised Regulations were issued covering this and other modifications in May, 1913.

The two cases which are compared are far from being analogous. In the case of the General Post Office the voltage on the wires and the power behind it are not such as are likely to cause any injury to person or animal through shock from a fallen wire; but it is very doubtful whether the G.P.O. figures are sufficiently conservative when one considers the extensive wrecking of telegraph and telephone lines which occurs in every snow-storm that is accompanied by a gale. High-tension power lines are on a different footing. It is the duty of the Board of Trade to prescribe reasonable precautions for safeguarding the public, etc., from fallen wires, and for the maintenance of a continuous supply of energy to those who are dependent on it. Having this duty laid on it by Act of Parliament it is not to be expected that the Board will err on the side of under-cautiousness, and, in view of a few failures of high-tension lines which occurred in the severe storm of January, 1913, in the case of lines that had been most carefully designed and erected to comply with the Board's Regulations, one can scarcely expect that the Board will make any further relaxation in its requirements for some time to come.

It does not seem to be generally understood that the Board is prepared to relax the Regulations in those cases in which it can be shown that wind pressures of 25 lb. per square foot have never been recorded. The Meteorological Department has extensive records of the wind pressures in all important districts of these islands, and they should be consulted prior to designing any line.

Mechanical Design Formulæ, Etc.

I. (A) *For wood poles.* (B) *For steel poles.*

(A) Full particulars of the dimensions of wood poles and 1-ft. breaking stresses are given in the British Post Office Technical Instructions, XIII, dated 1911. Valuable information on the strength, etc., of poles is also given in Mr. Christopher Wade's paper* before this Institution.

1. An A-pole is about $4\frac{1}{2}$ times as strong as a single pole comprising one of the legs, when provided with a creosoted brace-block 8 in. × 4 in. and 6 or 8 ft. long about 2 ft. from the butt end, and with an oak key near the top secured by a scarf-bolt and with a tie-bolt about half-way up the pole above the ground line, the spread of the pole being about one-eighth of the length. A second scarf-bolt is employed at the top of the pole.

2. An H-pole fitted with two cross-arms, one tie-rod, and one brace-block, but no trussing tackle, is about $3\frac{1}{4}$ times as strong as a single pole comprising one of its legs.

3. *To determine the size of pole required.*

Let d = diameter in inches of each line wire,
n = number of line wires,
p = wind pressure in lb. per square foot on a plane surface,
l = length of span in feet,
D = distance of centre of wires to ground-level in feet,
d' = average diameter of pole in inches,
D' = distance of pole out of ground in feet.

Take the effective area exposed to wind pressure as 0·60 of the actual diameter of line wires and poles multiplied by the respective lengths.

Then—

(*a*) Total wind pressure on the wires acting on the pole at the centre of the wires

$$= \frac{0{\cdot}6\, d \times n \times p \times l}{12 \times 112} = \frac{d \times n \times p \times l}{2240} \text{ cwt.}$$

(*b*) The resulting stress on the pole acting at 1 ft. from the ground-line is then—

$$\frac{d \times n \times p \times l \times D}{2240} \text{ cwt.}$$

(*c*) The wind pressure on the pole itself acting at 1 ft. from the ground-line

$$= \frac{0{\cdot}6\, d' \times D' \times p \times D'}{12 \times 2 \times 112} \text{ cwt.}$$

$$= \frac{d' \times D' \times p \times D'}{4480} \text{ cwt.}$$

(The wind pressure on A- and H-poles should be taken as $1\frac{1}{2}$ and $1\frac{3}{4}$ times respectively that on a single pole.)

Therefore, the total 1-ft. breaking stress acting on the pole is the sum of (*b*) and (*c*), and this should be multiplied by the factor of safety (10). The size of pole required can at once be determined by reference to P.O. Technical Instructions, XIII.

(B) For steel poles, Messrs. Bullers, Ltd., have kindly furnished the specification which is given in Appendix I.

II. *Stress on poles due to change in direction of wires.*

Let θ = the angle between the wires,
R = resultant stress in lb. acting along a line which bisects the angle θ,
p = stress of each span, *i.e.* the total breaking stress of all the wires in lb. divided by the factor of safety allowed for the wires.

* *Journal I.E.E.*, vol. 39, p. 304, 1907.

Then—

$$R = 2 \times p \times \cos \frac{\theta}{2} \text{ lb.}$$

This stress may be taken up by a stay calculated as in III.

III. *Stress in stays.*

Let S = stress in stay wire in lb.,
R = resultant stress of line wires in lb.,
θ = angle formed by stay wire and pole.

Then—

$$S = \frac{R}{\sin \theta} \text{ lb.}$$

IV. *Stress in terminal pole.*

This is equal to the total breaking stress of all the wires attached to it on the line side divided by the factor of safety to which they are stressed.

V. *Breaking stress of round insulator pins.*

Let W = elastic limit for wrought iron or mild steel,
L = length in inches above cross-arm,
D = diameter of pin in inches,
C = coefficient of rupture; 65 to 80 for wrought iron, and 80 to 100 for mild steel.

Then—

$$W = \frac{C \times 4{\cdot}7 \times \left(\frac{D}{2}\right)^3}{L}.$$

A factor of safety of 4 should be allowed for iron or steel pins in order to obtain sufficient stiffness.

VI. *Breaking stress, etc., of 7/8 and 19/8 S.W.G. galvanized steel stay wire.*

No. of wires...	7	19
Weight per 100 yards in lb. ...	151	415
Breaking stress in lb.:—		
25-ton quality	7,840	21,280
40-ton ,, ...	12,180	33,060

VII. *Average breaking stress for stay rods.*

⅝ in	10,650 lb.
¾ ,, ...	15,900 ,,
⅞ ,, ...	21,900 ,,
1 ,, ...	29,100 ,,

VIII. *Stay baulks.*

When buried so as to pull against undisturbed ground, stay baulks may be proportioned as follows:—

Evenly Distributed Load in Tons	Size of Baulk
12	3 ft. 6 in. × 10 in. × 5 in.
8	3 ,, 0 ,, × 9 ,, × 4½ ,,
5	2 ,, 0 ,, × 10 ,, × 5 ,,

IX *Strength of steel channel cross-arms.*

As stated elsewhere, galvanized channel 3½ in. × 2 in. × ¼ in. (B.S.C. No. 2) is commonly employed. There are very few data available for steel channels, but experiments show that the following formulæ may be safely used to give a factor of safety of 4 and ⅜-in. deflection on a single arm of this size of channel.

Let W = maximum weight in lb.,
and L = length in feet of channel arm.

(*a*) Channel with weight at one end (Fig. 2*a*)—

$$W = \frac{2750}{L}.$$

(*b*) Channel with weight in centre (Fig. 2*b*)—

$$W = \frac{5400}{L}.$$

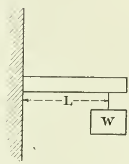

FIG. 2*a*.

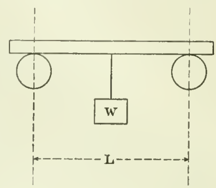

FIG. 2*b*.

X. *Particulars of catenary wires will be found in Appendix X.*

ELECTRICAL DESIGN FORMULÆ, ETC.

The following formulæ and particulars are in regular use in designing overhead lines and give very accurate results.

1. *To find current in lines.*

Let W = watts to be delivered at far end of line,
V = voltage between outer wires at delivery end,
$\cos\phi$ = power factor of the load,
I = current in amperes.

Then—

$$I = \frac{W}{V \cos\phi} \text{ for single-phase lines,}$$

$$I = \frac{W}{\sqrt{3}\, V \cos\phi} \text{ for 3-phase lines.}$$

2. *Voltage loss.*

For short lines such as are used in the United Kingdom, capacity may be ignored and the formula $V_g - V$ will give the voltage loss.

$$V_g = \sqrt{(V \cos\phi + V_R)^2 + (V \sin\phi + E)^2}$$

where V_g = voltage at generator,
V = voltage at point of use,
V_R = ohmic pressure-drop in volts,
E = E.M.F. of self-induction,
ϕ = angle of lag corresponding to power factor of load.

There is another and simpler method of ascertaining the loss when the following particulars are known :—

E.M.F. at point of use ; kilowatts to be delivered ; power factor of load ; size of wire ; distance between wires ; periodicity ; length of route.

In a continuous-current circuit the drop in voltage depends upon the current and the ohmic resistance. In an alternating-current circuit the total drop depends not only upon the current and the ohmic resistance, but also upon the self-induction of the circuit and the power factor of the load. In the short overhead lines used in this country the effects of electrostatic capacity may usually be ignored, and no account is here taken of it.

The pressure-drop due to resistance which would result were a continuous current to flow through the circuit, is first determined ; then a " drop factor " is found by which the pressure-drop with continuous current must be multiplied in order to obtain the pressure-drop produced by alternating current. The "drop factor" depends upon three things :—(1) the ratio between the ohmic value of self-induction (reactance) and the ohmic resistance ; (2) the power factor of the load ; and (3) the percentage value of the resistance pressure-drop.

(1) This depends upon the size of wire, the distance between wires, and the frequency. Appendix III gives the ratio of reactance to resistance for conditions which are most likely to occur in practice.

(2) The effect of the power factor of the load is given in Appendix IV, in which the " drop factors " for various ratios of reactance to resistance and various power factors are given. These have been determined by assuming a resistance loss in volts equal to 10 per cent of the pressure delivered.

(3) The percentage value of the resistance pressure-drop has a relatively small effect on the value of the " drop factor," so that the values given, which are determined for a resistance loss of 10 per cent, may be accepted as practically correct for all resistance values not exceeding 15 or 20 per cent. The greatest discrepancy occurs when the ratio is high and the power factor is unity.

3. *Self-induction.*

The coefficient of self-induction in millihenries per mile of single conductor is $0{\cdot}0805 + 0{\cdot}741 \log d/R$,

where d = distance between centres of conductors in inches, and R = radius of conductor in inches.

The ohmic value of self-induction is—

$$2\pi \times \text{periods per second} \times \text{henries}.$$

The E.M.F. of self-induction is—

$$2\pi \times \text{periods per second} \times \text{henries} \times \text{amperes flowing in the conductor}.$$

4. *Graphical method of ascertaining the losses in a 3-phase overhead line.*

In Fig. 3 B H J is drawn to scale as an equilateral triangle with each side equal to the pressure between the wires at the loaded end (B, H, and J, being the three phases). Then A B, or A H, or A J, are each equal to the pressure $\div \sqrt{3}$. Draw A C (to scale) equal to the full-load current at the loaded end, lagging behind A B by an angle ϕ corresponding to the power factor ($\cos\phi$) of the load. Draw A D at right angles to A B and of such a length as to represent the capacity current to the same scale as A C. This assumes that the capacity is massed at the loaded end. Compound A C and A D ; this gives the resultant current A E in the line.

Now draw B F (to the same scale as A B) to equal the pressure drop in one wire and parallel with A E. (This pressure drop is equal to A E $\times$ resistance of one wire.) Next draw F G (to the same scale as A B) at right angles to B F and equal to the E.M.F. of self-induction in one wire. Join A G. Then from A G complete the triangle G L K, and the sides G L, or L K, or K G, each give the necessary pressure between the wires at the generating end (*i.e.* $\sqrt{3} \times$ A G).

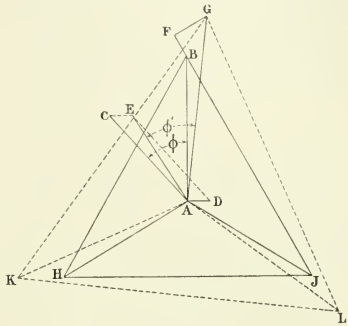

FIG. 3.

The cosine of the angle ϕ' is the power factor at the generating end, and therefore the kilowatts delivered to the line will be—

Pressure G L $\times \sqrt{3} \times$ amperes A E $\times \cos\phi' \div 1{,}000$.

5. *Electrostatic capacity.*

Overhead bare conductors.

Let C = capacity per mile in microfarads,
d = distance in inches between centres of wires,
r = radius of conductor in inches.

Then for a two-wire circuit—

$$C = \frac{0{\cdot}0194}{\log d/r}.$$

In the case of a 3-phase circuit with the conductors arranged at the corners of an equilateral triangle there are practically three equal capacities, as is shown in Fig. 4, and in this case the capacity

$$C_1 = \frac{0{\cdot}0388}{\log d/r}.$$

The capacity current in amperes per mile of cable (assuming that the wave-form of the E.M.F. is a sine curve) will be—

1. For a single-phase circuit $\dfrac{2\pi \times p \times C \times V}{10^6}$,

2. For a 3-phase circuit $\dfrac{2\pi \times p \times C_1 \times V/\sqrt{3}}{10^6}$,

where p = periods per second,
and V = voltage between two outer conductors.

Values for copper and aluminium conductors will be found in Appendices VI and VII.

In the case of conductors arranged in one plane the capacity is obtained from the expression $\sqrt[3]{abc}$, where a, b, c are the capacities shown in Fig. 5.

6. The Table of safe currents for overhead wires given in Appendix V is based on Professor George Forbes' formula, $I^2 = D^3\left(\frac{t\pi^2 H}{4R \times 0{\cdot}24}\right)$. This is found to be very accurate in practice.

Before discussing details it will be of interest to describe two lines representative of wood and steel pole construction. With one important exception most of the high-tension lines have been built with creosoted wood poles. A representative example of an up-to-date line using wood pole supports is that erected from Scotswood to Burn Pit for the Newcastle-upon-Tyne Electric Supply Company, to the specification of Messrs. Merz & McLellan.

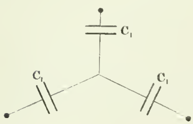

FIG. 4.

FIG. 5.

The main particulars of this line are as follows :—

System of working. 3-phase 40 cycles with earthed neutral.
Voltage between conductors. 20,000.
Voltage between conductors to earth. $20{,}000 \div \sqrt{3}$.
Conductors. Two horizontal circuits employing wires of 0·10 sq. in. section, arranged on the Merz-Hunter split conductor system.
Conductor spacing. 5 ft. horizontally. 5 ft. vertically.
Conductor sag at 60° Fahr. 5 ft. 6 in.
Average length of span. 85 yards.
Straight line poles. H-poles 32 ft. long and 10½ in. diam. at 5 ft. from the butt. 3 ft. 6 in. centre to centre of poles.
Channel arms on straight line poles. 10 ft. 6 in. long. 3½ in. × 2 in. × ¼ in. galvanized.
Terminal poles. H-poles 40 ft. long and 11 in. diam. at 5 ft. from the butt. 12 ft. centre to centre of poles.
Channels on terminal poles. 12 ft. 6 in. long. 5 in. × 2½ in. × ⅜ in. galvanized.
Corner poles. H-poles 40 ft. long and 10½ in. at 5 ft. from the butt. 3 ft. 6 in. centre to centre of poles.
Channels on corner poles. 12 ft. 6 in. long.
Insulators on straight line poles. Petticoat pin-type well-cushioned from the metal pin by oiled twine packing.
Insulators on corner poles. Petticoat pin-type well-cushioned from the metal pin by oiled twine packing, but with a second insulator.
Insulators on terminal poles. Suspension type. Three in series.
Earthing arrangements. A continuous 7/12 S.W.G. galvanized steel strand is run from end to end and is connected to an earth plate at every fifth pole. All metal-work on the poles is connected to this wire.
Telephone system. Four-pair telephone cable arranged for superimposed working is suspended from the continuous earth wire. Low-tension telephones are used.
Factors of safety. Strictly in accordance with the Board of Trade requirements of 1913.
Guarding. As shown in Fig. 15.
The terminal pole on the above line is illustrated in Fig. 6, and a corner pole in Fig. 7.

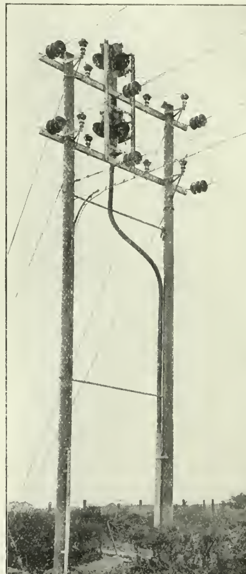

FIG. 6.—Terminal Pole.

The most important lines in the United Kingdom on which steel towers are used are those of the Cornwall Electric Power Company, for whom Mr. J. S. Highfield is the consulting engineer. The North Wales Power Company also have a few miles of lattice steel pole line. The Cornwall Power Company have used both tubular and lattice steel poles on 11,000-volt lines with spans of 240 ft. and 350–360 ft.

The principal features of these lines are as follows :—

Steel pole line (No. 1).

Conductors. Two vertical circuits employing solid hard-drawn copper wire, partly 0·125 sq. in. section, continuing with 0·07 sq. in.

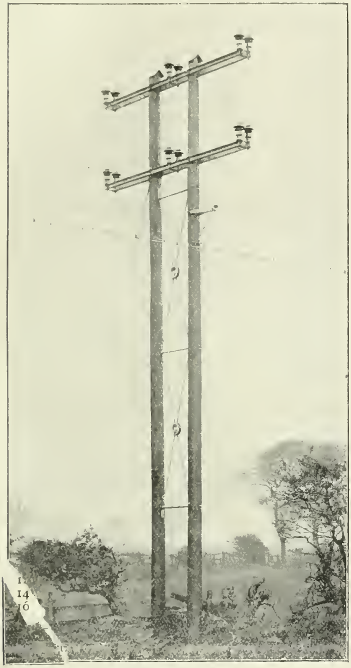

FIG. 7.—Corner Pole.

Conductor spacing. Two top phases 9 ft. 6 in. apart ; two middle phases 10 ft. 6 in. apart ; bottom phases 11 ft. 6 in. apart. Distance between each phase vertically 4 ft.

Conductor sag at 60° Fahr. On the 0·125 sq. in. section 11 ft., and on the 0·07 sq. in. section 10 ft.

Average length of span. 117 yards.

Straight line pole. Total length 50 ft. 8 in. These poles consist of three sections, end base 6 ft. long, and two sections above ground of 19 ft. 4 in. and 25 ft. 4 in., built up of four main angles and braced with similar angles.

Angle poles. Total length 51 ft. 8 in. These poles consist of three sections, one 7 ft. base and two sections above ground 19 ft. 4 in. × 25 ft. 4 in., built up of four main angles forming a 10 ft. 6 in. square at the ground-level, tapering to a 9-in. square at the top.

Insulators (straight line). Grey suspension type, two in series.

Strain insulators. The same as the straight-line insulators with a different fitting for clamping the wire.

Earthing. A continuous 7/13 S.W.G. phosphor-bronze stranded wire is run from end to end and earthed at five points on the line.

Road crossings. Four poles are placed in the hedge adjoining the road, from which cross wires are supported so that in the event of the power wire breaking it falls on this net. The net is earthed. Barbed wire is wound round the pole at a height of 8 ft. from the ground.

Danger notices. These are placed on every fifth pole and each pole adjacent to the roadways.

Steel pole line (No. 2).

The general construction of this line is similar to that of No. 1. Some of the poles are, however, of a different type, consisting of steel tubes braced together so as to make an A-pole.

Conductors. Two vertical circuits, employing wire of 0·07 sq. in. section.

Conductor spacing. 9 ft. 6 in., 10 ft. 6 in., 11 ft. 6 in. horizontally, and 4 ft. between phases vertically.

Sag at 60° F. 10 ft.

Average length of span. 119 yards.

Insulators. Suspension type, two insulators in series, with phosphor-bronze stranded-wire grummets.

Earthing arrangements. One continuous 7/13 S.W.G. phosphor-bronze stranded wire run from end to end, and connected to earth where a satisfactory earth can be found.

WOOD AND STEEL POLES.

Most of the work already carried out has been done with winter-felled red-fir poles, creosoted by the Bethell process to the G.P.O. standard of an average of 10 lb. of creosote per cubic foot of timber. There is good reason to anticipate a life of 35 to 50 years for these poles if they are left undisturbed and if they are erected within a few months after creosoting. The reason for this is that the free creosote drains into the earth around the pole and forms an additional germicide protection.

In the last two years much interest has been taken in poles creosoted by the Rueping process, but naturally there is no experience yet of their life on the few lines which have been erected in this country. The poles have some advantages over Bethell poles in that they are both lighter in weight and cleaner to handle. From these points of view and in face of the experience obtained in other countries, poles treated by the Powell saccharine process must also be seriously considered in future.

To obtain the best results it is essential that all poles should be selected, dressed, slotted, bored, etc., at the maker's works before the creosoting is done. The maker should be supplied with detailed drawings showing the

finished result required, and the inspection of the poles should take place at his yard whenever possible. When the poles are built up at the maker's works the key-block of A-poles and the brace-blocks of A- and H-poles must be properly marked so as to ensure that they are put together correctly again on the site. Any recess cut in a pole after creosoting should be painted with hot tar. Some engineers have the bottom 9 ft. of the pole covered before erection with a preservative mixture consisting of $1\frac{1}{2}$ parts each of Stockholm tar and slaked lime and 7 parts of well-boiled gas tar.

Steel structures before delivery should be coated with bitumastic solution; and on that part of the structure which carries the insulators and so is normally inaccessible with safety, the members should also be galvanized before applying the solution.

The choice between steel and wood poles is mainly a question of first cost plus maintenance charges. In the industrial districts of this country there are many reasons why pole lines cannot be run in a straight line, with the result that the spans usually do not exceed 85 yards in length. For such spans it is cheaper in first cost to employ wood poles which require no after-maintenance. Under exceptional conditions, such as in Cornwall, longer spans can be used, and steel poles can then undoubtedly be employed with advantage. In the author's opinion steel poles should not be employed in smoke and fume-laden districts without the most careful investigation, because experience with them on tramway and railway systems has shown that their rate of deterioration is rapid and the cost of maintenance in painting, etc., is high.

Corner poles of wood.—On most lines it is best to deal with angles by using H-poles which are, when necessary, braced with trussing tackle, and which are equipped with stays and are erected so as to bisect the angle. On heavy double-circuit lines at severe corners it is sometimes necessary to use well-braced 3-legged structures. All corner poles should be erected with only sufficient rake to allow for settlement of the ground, and the whole of the side strain should be taken up by the use of stay wires and kicking blocks. In loose or marshy ground it is often necessary to plant corner poles as well as the kicking blocks in concrete. At corner poles the line wire should be eased round the curve by using two insulators as shown in Fig. 7, and more especially so when solid wire is employed.

Galvanizing, sherardizing, etc., of metal-work.—All channel arms, pins, stay rods, brackets, bolts, etc., should be thoroughly galvanized to the usual standard specification, and where the threads of bolts, etc., are too small to be brushed out while wet in the galvanizing process they should be separately sherardized. Sherardized articles sometimes appear to be rusty after some months' use in the open, but this is only a surface effect.

Stays.—All stay wires should conform with the Engineering Standards Committee's Specification No. 16 for galvanized wire for mechanical purposes. Convenient standard sizes to use are 7/8 and 19/8 S.W.G. galvanized steel strands, which should not in the author's opinion have a breaking strain exceeding 33 tons per square inch, as otherwise the wires will be too hard to be properly workable when nozzling off. The stay wire should be taken three times round the pole or, alternatively, galvanized iron plates should be fitted to wooden poles, at the point where the stay is fixed, to prevent cutting into the wood. The stay should be taken round a galvanized thimble at the stay rod end. All stay wires should be connected to the general earthing system of a line; but when lines are run in mountainous country where it is difficult to obtain good "earths," it is advisable to insulate the stay wire near the pole by inserting in it an insulator of the tramway globe strain type.

Sometimes it is necessary to put fore and aft stays on poles, *e.g.* where a line is liable to be damaged by aeroplanes. Selected poles should have stays in the direction of the line whenever the line makes any considerable variation in level. On unenclosed land, so as not to cause injury to animals, all stay rods should be protected by means of wooden cattle-guards securely fixed and painted white to make them easily discernible. It would be better to treat them by the Burnett or Powell processes before painting. The creosoting of cattle guards is a mistake in such cases because they cannot then be painted. In all other cases the cattle guards should be preserved by creosoting them.

The nozzles of all stays should be protected from corrosion by being coated with a high-grade bitumastic paint, and unless the threads of all stay rods are galvanized they should be painted with a mixture of 45 parts tallow, 45 parts coal tar, and 10 parts of mineral pitch, as soon as practicable after installation, to prevent them rusting and becoming useless. In all smoke and fume-laden districts it would be a great improvement to paint all steel and iron work over the galvanizing.

Line Conductors.

Probably 95 per cent of the high-tension lines are equipped with copper conductors, chiefly because that metal was first in the field, and while it is very uniform in its characteristics it also has a high scrap value compared with its original cost. Our knowledge of aluminium has, however, made rapid strides in the last three years, and it has now become a competitor that can no longer be passed over without serious consideration. For instance, cold rolling, coupled with improved manufacturing processes in the United Kingdom, has increased the breaking [illegible] of aluminium by 10 per cent over that obtained onl[illegible]ee years ago. After having erected and watched the [illegible]our of about 500,000 yards of aluminium conductors [illegible]y on low-tension lines), the author is very decidedly of the opinion that this metal ought not to be passed over in favour of copper if the total first cost of a line comes out cheaper with aluminium. In cases where sulphur products abound, *e.g.* in the neighbourhood of coke ovens, aluminium is preferable to copper because it will not be so readily corroded.

The following are some of the high-tension lines on which aluminium has been successfully employed:—

1. War Office, 3-phase lines from Aldershot to Ewshott, etc.
2. War Office, 3-phase lines from Tidworth to Bulford.
3. Weardale Steel, Iron, and Coal Company, Thornley to Wingate.
4. Ebbw Vale Steel, Iron and Coal Company.
5. North Wales Power and Traction Company.
6. Fife Coal Company.

There is no standard practice in the case of copper in regard to the use of solid or stranded conductors. On spans up to 50 yards tramway practice may very safely be followed in using solid wires from $11\frac{1}{2}$ S.W.G. up to 4/0 S.W.G. For longer spans and larger sections the conductors should certainly be stranded because of the additional strength obtainable, and 7, 19, or 37-strand conductors will be suitable. When specifying the breaking strain of the copper, it is very useful to employ a formula of the form suggested by Mr. A. P. Trotter :—

$$T = 30 - 20 D,$$

where T = breaking strain of each wire in tons per sq. in., D = diameter of wire in inches.

In other respects the copper should comply with the British Engineering Standards Specification No. 7, dated March, 1910. The "limit of proportionality" on the wire may be taken at 75 per cent, and the minimum size of solid copper conductor now allowed by the Board of Trade on a high-tension line is No. $11\frac{1}{2}$ S.W.G.

With aluminium it is essential to use stranded conductors, and there should never be less than seven wires in the strand. The breaking strain of the wires employed in the strand can be obtained from a formula similar to the above, viz.—

$$T = 16{\cdot}5 - 24 D.$$

In order to obtain suitable wire it is suggested that the specification should call for wire having a "limit of proportionality" of 70 per cent approximately, and conforming after stranding with the tests set out in the following Table :—

Suggested Tests for Hard-drawn Aluminium Conductors.

Standard Wire Gauge	Diameter of Wire. Inches	Breaking-strain. Tons per Sq. In.	Extension on a 5-in. length. Per Cent	Wrapping Test
4	0·232	11·00	3·00	Three times round its own diameter on and three times off.
6	0·192	12·00	3·00	
8	0·160	13·00	3·00	
10	0·128	13·50	3·00	
12	0·104	14·00	2·50	
14	0·080	14·50	2·50	
16	0·064	14·75	2·50	

The object of the "wrap test" is to ensure that no brittle wire is used, and it should be noted that compliance with the Board of Trade Regulations is only obtainable by ignoring wires larger than No. 6 S.W.G.

In Appendix VIII a comparison is given of the principal physical, mechanical, and electrical properties of aluminium and copper revised in accordance with the latest information, and in Appendix IX will be found a stranding table for both copper and aluminium conductors, while the sag to be given in erecting a conductor can be obtained from the formulæ set out in Appendix II, allowing a factor of safety of 5 for copper and aluminium at 22° Fahr., when account is taken of the stress due to its weight and to wind, but excluding its elasticity. Wind pressure is to be taken at 25 lb. per square foot, and the effective area of the conductor should be taken as 0·6 of the diameter multiplied by the length, and no allowance need then be made for the possible accumulation of ice and snow.

Jointing conductors.—It is usual to make all joints at insulators and not under strain. There are many ways in which copper conductors can be jointed. The best way known to the author for jointing copper on lines which have to carry heavy loads is by means of the copper braids described by Mr. C. Vernier before this Institution.* During calm weather there is no difficulty in making excellent butt-welded joints with blow-lamps on aluminium conductors up to 0·25 sq. in. section, which is the largest section that is likely to be employed in high-tension work.

Spacing of Conductors.

Bracket arms, brackets, and pole roofs.—Frequently on single poles carrying one 3-phase circuit a triangular spacing of the conductors is obtained by placing one insulator on a ridge-iron above the zinc pole roof (with which all poles should be fitted) and two insulators on a horizontal arm below it. While this arrangement economizes space, it is not to be recommended because the pole roof is liable to be damaged and because it is difficult to make the top insulator-support sufficiently rigid in all positions, particularly on curves. A better arrangement is that obtained by using three galvanized wrought-iron brackets. Two of these can be arranged on one side and one on the other side of the pole, or they can be put all on one side of the pole if there is any possibility of a second circuit being required later. (In passing, it should be noted that no pole roofs of lighter gauge than No. 14 S.W.G. zinc or No. 16 galvanized iron should be used. Anything lighter is of no use in high winds.) In all really heavy work, such as a duplicate-circuit line, steel channel and not wood cross-arms are now generally used, and there is a growing practice to abandon the equilateral triangular arrangement of the wires on 3-phase duplicate circuits, and to erect the wires of each circuit either vertically or horizontally. The latter is the better arrangement when duplicate circuits are needed, as trouble has been experienced with the vertical arrangement through snow loading down an upper wire until it fouled a lower wire. When duplicate circuits are needed it is an excellent plan to place one circuit on a single pole and the second on another single pole at least one pole length away from it if wayleaves can be arranged. The great advantages of this plan are :—

One circuit can be shut down for repairs, etc., enabling the wiremen to work in safety and quickly, and it is easier to arrange for supply to be given on a ring-main system. The second line should be taken by a different route when possible.

It is not possible to give any general rule as to the spacing to be adopted for conductors for any particular voltage, as this varies with (1) the size of conductor, (2) the length of span, (3) the windage, (4) the sag, and (5) the horizontal or vertical arrangement of the wires; but it may be taken that the spacing on any length of span should not be less than—

3 ft.	for 20,000 volts
2 ,, 6 in.	,, 11,000 ,,
2 ,,	,, 6,000 ,,
2 ,,	,, 3,000 ,,

* *Journal I.E.E.*, vol. 47, p. 313, 1911.

In deciding the spacing, it is necessary to know the maximum angle of swing of the conductors.

Let θ = maximum angle of swing.

Then—

$$\tan \theta = \frac{\text{wind pressure per foot of conductor}}{\text{weight per foot of conductor}}.$$

The maximum deflection in feet from the vertical is $\sin \theta \times$ sag in feet. In Appendix XI values of $\sin \theta$ are given for copper and the equivalent aluminium conductors for wind pressures of both 17 and 25 lb. per sq. foot. In order to prevent two conductors in a horizontal plane from swinging together, they should, theoretically, be suspended so that their distance apart is more than twice the maximum deflection, but in practice it is safe to assume that the wires will not swing "dead out of phase," and on 80-yard spans to make the spacing equal to the sag of the conductors at 60° F.

Galvanized channel arm of $3\frac{1}{2}$ in. × 2 in. × $\frac{1}{4}$ in. standard section is one which is found most useful. The channel arms, being earthed, have one disadvantage on lines which are operated with an earthed neutral and are controlled by any form of instantaneous overload or automatic protective apparatus. Big birds, chiefly crows, stand on the arms and peck at the live wires with results altogether disastrous to themselves, but involving nothing worse than a shut-down of the line and an interruption of the supply. This trouble is usually experienced from May to August while crows are young and presumably learning wisdom. The difficulty has been overcome on several lines by providing porcelain bushes round the insulator pins from the channel arms upwards into the insulator and by clipping pieces of bitumenized fibre conduit on to the arm so as to insulate the bird. On delta-connected lines birds are frequently killed, but no shut-down of the line is involved.

Tying-in of Conductors.

This is one of the most important features in the construction of any line, as bad work will lead to endless trouble and cost in maintenance.

There are three principal methods of tying-in the conductors to the insulators:—

1. Flexible binders.
2. Semi-rigid binders.
3. Rigid clamps.

1. In the author's opinion the flexible binder demands the services of skilful wiremen and is the best both for

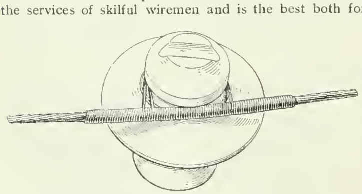

Fig. 8.—Flexible Copper Binder.

copper and aluminium if it is made correctly. Fig. 8 shows the copper binder which has stood the test of several years' work on the Newcastle-upon-Tyne Electric Supply Company's lines and has never been known to fail. Fig. 9 shows the successful aluminium binder used on the War Office lines at Aldershot and developed on suggestions

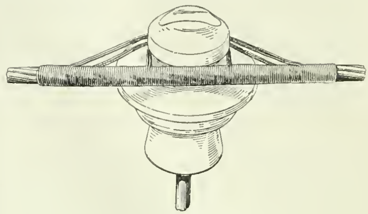

Fig. 9.—Flexible Aluminium Binder.

made by Mr. S. B. Donkin for line conductors up to 0·10 sq. in. For larger conductors the binder shown in Fig. 8 is quite suitable. In both these designs one essential feature is the "pigeon" or chafer of wire to prevent abrasion of the line wire and of the glaze on the porcelain. Another feature is that flexibility is obtained without the possibility of longitudinal movement of the conductor.

2. The only semi-rigid binder known to the author is that designed and patented* by Mr. G. K. Paton, Chief Engineer of the North Wales Power & Traction Company, and used successfully by him both on $72\frac{1}{2}$ miles of single circuit employing solid copper conductors varying from No. 4 to 20 S.W.G. and on 8 miles of single circuit composed of stranded aluminium. The binders have also been used extensively by the Ebbw Vale Steel Company and the Lambton & Hetton Colliery Company. The Paton binder was designed to overcome troubles on lines which run over mountains and are subject to very severe weather in winter. Under these conditions it was found that the soft-copper flexible binders originally installed stretched and left the line wire loose at the insulator. Vibration in the line wire then caused chafing both of the wire and of the insulator groove, in which the glaze was broken away. Cases were found where the line wire had worn away for 30 per cent of its diameter, while many insulators failed at the groove. The Paton binder is illustrated in Fig. 10. It is made of solid copper wire, No. 4 to No. 6 S.W.G., according to the size of the line wires of copper. With aluminium lines the aluminium binder varies from No. 2 to No. 6 S.W.G. The binder is formed on a special jig to clip round the neck of the insulator, a standard jig being made for each size of insulator. The binder is hooked on the line wire and then bound under tension at the other end with about 15 turns of No. 14 S.W.G. soft binding wire. A leather or pig-skin chafer is fixed between the line wire and the neck of the insulator, and after 5 years' use it has been found that the chafer remains as good as new and completely stops the chafing effects on the wire and the insulator. The whole binder remains tight and is yet flexible owing to the cushioning effect of the chafer. The cost is about the same as that of a well-made

* Patent No. 5,636, 1912.

flexible copper binder, and about one-fourth the cost of some mechanical clips. It has an advantage over the flexible binder in that no special skill is required for fixing it.

3. There are various forms of rigid clamps in extensive use. When rigid clamps are very carefully fitted by experienced wiremen they appear to give satisfaction, but it is necessary to emphasize the fact that, to get good results, each clamp should be fitted to the insulator on which it is to be used because of the variations in dimensions of all insulators. Some years ago the author investigated two lines on which troubles were experienced, and found that these were due to mechanical clamps. In one case, although well fitted, the line vibration had caused crystallization and breakage of the metal of the clamps. In the other the clamps had been so badly fitted that they were moving, with the result that the glaze of the insulators broke and caused the insulators to fail.

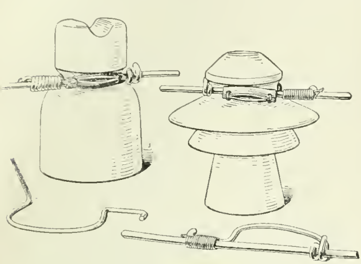

FIG. 10.—Paton Semi-rigid Binder.

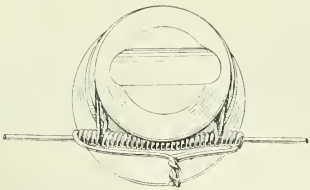

FIG. 11.—Flexible Telephone Binder.

The author is of opinion that rigid clamps are wrong in principle because they reflect back vibrations in the line wire, and it seems certain that ultimately the line wires must crystallize and break at these clamps even if the clamps do not fail first. In this matter much experience has been gained from the breakage of tramway trolley wires at rigid supporting ears.

Method of making a telephone-line binder (*Fig.* 11).—A cushion, of say 24 turns, is first made on the line wire, and the two ends are then taken around the insulator; in order to avoid having a cross at the back, the wire which starts under the line wire is kept at the bottom of the groove and under the line wire at the other side, and similarly the other wire is kept at the top of the groove and over the line wire. Not less than four turns are now made round the line wire on each side, and the ends are brought together and twisted to prevent the binder spreading.

INSULATORS.

The pin type of insulator is most in favour in this country, and is likely to continue so while pressures remain at 20,000 volts; indeed it is quite reliable up to 66,000 volts. The suspension type of insulator is more suitable for really high pressures such as 100,000 volts, and is then the only practicable way of insulating the conductors. We have seen already that the working voltage has scarcely any influence on the first cost of a line, and the author would like to put forward the suggestion that in view of the rapidly increasing loads in industrial districts all main lines should be designed so that they may ultimately be worked at a higher pressure than that at which they are first operated. For instance, 6,000- and 11,000-volt lines might be designed for a pressure of 20,000 volts, and 20,000-volt lines for 40,000 or 50,000 volts. There can be no doubt that the time is approaching when there must be a further raising of working pressures on main alternating-current high-tension circuits, similar to the big change which was made in passing from 11,000 to 20,000 volts on underground cables eight years ago. The only commercially possible alternative would appear to be the Thury high-tension continuous-current system which has been described before this Institution by Mr. J. S. Highfield on three occasions.*

There is no difficulty in obtaining excellent pin-type insulators, but unfortunately many of those in use have not been of British manufacture. It must be placed to the credit of one British firm of porcelain-makers that it has taken up this question vigorously in the last few years. Late deliveries of insulators by foreign makers are very frequent, and several months sometimes elapse before an order for a few gross of 20,000-volt insulators is completed.

Whether insulators are made in two parts, or not, it is of the utmost importance to insist on the parts being put together in such a way that no air cavity can exist. In two-part insulators this can readily be done by putting in the filling cement very slowly when it is rather liquid. The cement must also be guaranteed to be such that it will not swell or deteriorate on prolonged exposure to damp air.

The colour of the insulators is of importance. Most engineers prefer brown, green, or neutral-tinted insulators as being less conspicuous than white and therefore less likely to attract the attention of stone-throwers, etc. White insulators have the advantage of more readily disclosing where a breakdown has occurred. On lines comprising two or more circuits it is sometimes advantageous to use insulators of different colours for each circuit in order to prevent mistakes and danger to linesmen. All insulators should be made of the highest grade porcelain which has been vitrified throughout and is

* *Journal I.E.E.*, vol. 38, p. 471, 1907; vol. 49, p. 848, 1912; and vol. 51, p. 460, 1913.

absolutely non-absorbent of moisture and free from flaws, cracks, or foreign matter. The colouring of insulators is given by the glaze which must cover the entire surface, except the area where joints are made, and must be free from crazing, bubbles, cracks, etc. On completion, insulators should be tested both electrically and mechanically. Messrs. Bullers, Ltd., have kindly furnished the specification given in Appendix XII of the tests which are recommended for proving the correctness of the design and quality of materials.

Suspension-type insulators can be very usefully employed at terminal poles for insulating the line wires in place of shackle insulators or insulators on pins or swannecks (see Fig. 6). Such an arrangement materially reduces the cost of a terminal pole on a heavy line. The practice of using shackle insulators on high-tension lines at terminal and corner poles is now almost extinct and is to be condemned because of the weakness of the insulator from the electrical point of view. All telephone-circuit insulators should be of the double-petticoat type when used under power wires.

Insulator pins and fixing.—It is important that all pins should be galvanized and should be stiff enough to withstand every normal strain. They may be fastened to the insulator by a cement which will not swell on prolonged exposure to damp air, or by packing the free space with hemp or twine soaked in linseed oil in such a way as to ensure that the insulator cannot work loose. Both methods have their advocates. The former is to be preferred where skilled labour is not readily obtainable. The latter method requires considerable skill to ensure satisfactory work, but, when properly done, the author prefers it because of the cushioning effect which is obtained.

Earthing Arrangements.

On all the best work a continuous earth-wire, varying in size according to the conditions, is run from end to end of the line either above or below the power wires, and all metal-work on the poles, including a lightning spike, is substantially connected to it. The earth-wire itself should be connected to an earth-plate at every fifth pole by means of a conductor (of ample section for carrying the possible leakage current) which is protected from mechanical damage above ground by a creosoted wood strip or other means, and from corrosion below ground by being buried in pitch or by being painted with a high-class paint such as P. & B.

The connection to the earth-plate must be well made to secure permanent results. One way which the author prefers is to have two bosses cast on the earth-plate with 8-in. centres and to drift into these the terminals of a standard copper tramway bond, to which is bound and soldered the conductor from above. These connections should be liberally painted as before. The earth-plate itself should be 18 in. square and of cast iron not less than ½ in. thick, and should be buried in small coke. Experiments have shown that this is the most efficient size of plate to use. Earth-plates may consist of a number of stakes driven into the ground and cross-connected, or of a 9-ft. cast-iron pipe buried in coke after cleaning off the Angus Smith solution. The author wishes to lay special stress on the necessity of great care being taken with the installation of the earthing system and its subsequent maintenance, as the safety of human life may be dependent on it. Some high-tension lines are in existence on which each pole has a separate earth-wire coiled up below the base of the pole, and not protected so as to make it impossible for people or animals to come in contact with it above ground. The author believes this arrangement to be really dangerous and would suggest the need for reconstruction.

Protection against Atmospheric Disturbances.

When the continuous earth-wire is run above the power wires it is usually placed there with the intention of also affording some relief from atmospheric disturbances, but not from direct lightning strokes. When placed above the power lines, the earth-wire should undoubtedly be of the same metal as the power lines or of bronze, and not of galvanized steel, which has a shorter life than these metals and will, on breaking, foul the power wires and interrupt the supply. This view has previously been put before this Institution by Mr. J. S. Highfield and the author,* who believes that no necessity exists in this country for earth-wire protection above the power lines, as experience of operating high-tension lines shows that lightning troubles are very few and are no more frequent than are mechanical faults on underground cables.

The following are the most important methods which are in use for protection against lightning effects :—

1. Air-core choking coils consisting of not less than 12 turns of line wire are installed in series with each line wire to hold back the high-frequency oscillations until a horn-type air-gap arrester placed on the line side of the coil can spark over. In series with the arrester a non-inductive resistance is employed to limit the flow of current to earth to, say, 10 amperes, and for this purpose a carbon-rod resistance may be employed.

The author does not place any faith in horn arresters erected in the open air, especially in industrial districts, as the air-gap varies in length due to corrosion and deposits of coal and other dust, and, therefore, requires too much attention. Also it has been shown by various investigators that the pressure in the line cannot be relieved by a spark-gap by more than 20 per cent if the series resistance is designed correctly to prevent surging at the frequency of the supply. The author is strongly of opinion that any form of arrester which involves a spark-gap is wrong in principle because of the high-frequency oscillatory disturbances caused by a spark in the circuit.† Serious damage to plant may be caused by these disturbances unless means are also provided to limit the disturbances to the line itself.

2. Electrolytic aluminium arresters combined with a horn arrester have been used on a small scale, but their extensive use is limited by the fact that they need re-charging every day from the line, and this cannot be done without considerable expense from locked-up static sub-stations. Full particulars of these arresters have been given by Mr. J. S. Peck.‡

3. Moscicki condensers are coming into favour slowly, possibly because of their high first cost. They have been

* *Journal I.E.E.*, vol. 46, p. 489, 1911, and vol. 51, p. 35, 1913.

† This was written before Mr. Duddell delivered his Presidential Address. The section on "Arcs and Sparks" contains several passages which confirm this opinion. *Journal I.E.E.*, vol. 52, No. 223, p. 1.

‡ *Journal I.E.E.*, vol. 40, p. 498, 1908.

used by the North Wales Power & Traction Company for some years with excellent results, and they are always installed as a matter of course on new lines. They have also been adopted recently by Messrs. Kennedy & Jenkin for the War Office lines from Tidworth to Bulford. The neat arrangement of this arrester on the terminal pole at Tidworth is shown in Fig. 12. The condenser arrester is

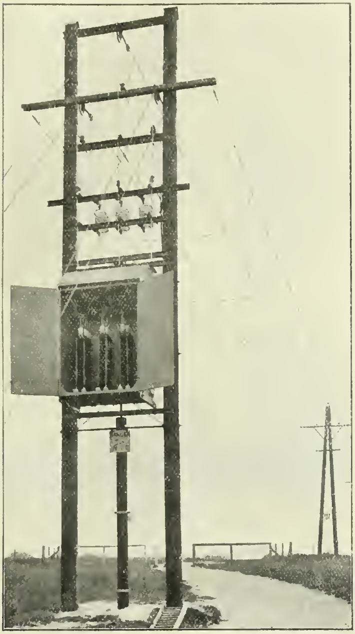

FIG. 12.—Terminal Pole, showing Moscicki Condenser.

attractive from the fact that it is automatic in action and able to discharge rapidly high-frequency disturbances in the line, while it only needs occasional inspection for the replacement of any blown fuses. It may be well to add that these condensers have not sufficient capacity to afford any improvement in the power factor of a line.

4. After much trouble with horn arresters, Messrs. Merz & McLellan have discarded arresters on all lines which are connected to the system through step-up and step-down transformers, and instead they deal with the problem in a novel way. About 10 per cent of the end turns on the line side of the transformers are insulated with special materials to a thickness of 300 to 400 per cent of the insulation on the remaining turns, and what is required is now well understood by transformer manufacturers. Atmospheric disturbances on the line are reflected back by the end turns of the transformers, and the oscillations are damped out by the ohmic resistance of the line. As the line wires are erected on high-quality insulators it will be seen that only a very high pressure on the line, *e.g.* a direct lightning stroke, will break down the insulation, and in practice it is found that the outdoor insulators are punctured and the station apparatus is unaffected. The arrangement adopted is effective and cheap and is easily worked in with the general design.

Probably some of the good results on all Messrs. Merz & McLellan's lines are due to their practice of connecting up their lines at both ends through paper-insulated cables, which have a very high resistance to breakdown when momentarily subjected to abnormal pressures. These cables have a low capacity and afford a permanent path to earth for high-frequency oscillations, and thus they are similar in action to the Moscicki condensers.

Telephone and Pilot Circuits.

Many lines are provided with private telephone circuits and with circuits for the operation of the well-known Merz-Price protective gear. These circuits may be combined in one paper-insulated cable protected by a lead sheath, to which antimony or not less than $2\frac{1}{2}$ per cent of tin is added for the purpose of hardening the sheath. Where two or more telephone circuits are required the cable may be of the multiple-twin type arranged to allow of superimposed working. In any case, for mechanical reasons, the insulation on the telephone conductors should be of the dry, solid type, as its capacity while being higher than that of the air-spaced type is not important on lines up to 40 miles long.

The suspension of the sheathed cable is usually done from the steel-stranded continuous earth-wire when it is run below the power wires. In this case the steel strand should be of 40-ton quality, and the sag given to it and the suspended cable should be such that, on completion, the combination runs parallel to the line wires if possible. The size of suspension strand required may be obtained by reference to Appendix X.

There have been several failures of plain lead-sheathed cables due to the omission of the tin in the sheath and to improper suspension. The difficulties have been very thoroughly investigated, with the result that an entirely satisfactory solution of the difficulty has been found and patented by Mr. C. E. Elder. About 110 miles of lead-sheathed cable on transmission lines have been erected in the Newcastle district under the Elder system during the past two years with such uniformly excellent results that it cannot be made too widely known. Briefly, the system consists of very short chrome-leather hangers which support the cable at every foot and which are prevented from having longitudinal movement by galvanized wire clips sprung on the suspension strand. On level routes every tenth hanger is also clamped to the cable by a galvanized flat spring clip, but on steep hills every hanger should be clamped. Fig. 13 shows the form of the Elder hanger usually employed.

In suspending lead-covered cables on spans exceeding 50 yards measures should be taken to secure that the cable has no severe bends in the vertical plane; and it is thus suspended as shown in Fig. 6. At horizontal bends the cable must be carefully led round the curve by pull-offs on the suspension strand. At terminal poles provision must also be made to carry the cable round an easy bend from the horizontal to the vertical plane in such a way that no movement can take place which would crystallize the lead sheath. The lead sheath should be definitely bonded at every fifth pole to the supporting earth-wire in order to carry away any charges which may be induced in it by the power wires.

FIG. 13.—The "Elder" Hanger.

On lines which are not protected with automatic gear requiring a pilot cable for its operation and on which one metallic telephone circuit only is required, it is usual to run two No. 14 S.W.G. phosphor-bronze or hard-drawn copper wires, and of these copper is to be preferred. They may be rotated so as to make one complete revolution at every fifth pole, and in this case it is also advisable to transpose the power wires twice on each route at regular intervals. The rotating arrangement of telephone wires is very unsymmetrical relative to the line wires, but it gives fair results in practice. The author prefers the simpler plan of not transposing the power wires and of not rotating the telephone wires, but of running the latter parallel to one another and transposing them at such regular intervals as may be required. Fig. 14 shows a simple arrangement for effecting the transposition. The author thinks that the cheapness of bare telephone-wire circuits is the only consideration which justifies them. The telephones are most needed at times of breakdown on the overhead line, and then if a power wire is broken the telephone wires may be either "alive" or burnt through if not already broken by a heavier wire falling on them. Failing these, the telephone circuit may be useless through a broken wire coiling round and short-circuiting it, or vice versa.

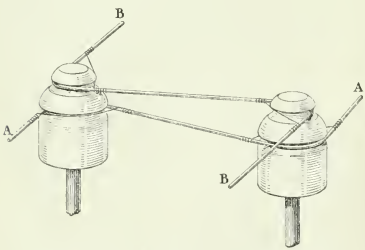

FIG. 14.—Showing a Method of Transposition of Telephone Wires.

TELEPHONES.

When bare telephone wires are used the only instruments which are permissible are those known as high-tension telephones, which are specially insulated in order to make it impossible for the telephone user to get a shock due to the considerable voltage which is induced on these wires under normal working conditions, or to contact between the telephone and power wires. A much favoured high-tension telephone apparatus is that made by Messrs. Siemens Brothers & Co., Ltd. It is of the remote-operated pattern, the transmitting and receiving parts being mounted on the back of a marble panel. It is connected to the line through a transformer and the sound is transmitted by insulated hearing tubes so that the user is not brought into contact with any current-carrying part of the apparatus. The protective devices consist of a combination of high-tension fuses and a patent combined vacuum and spark-gap protector. The arrangement described is primarily intended for use at the power house and sub-stations, but there is also a convenient portable equipment for attachment to the telephone wires anywhere on the route or at water-tight protected plugs fixed at definite points. The system is designed to work in proximity to a transmission line with the load balanced between the phases. Should the load be an unbalanced one, it is necessary to fit

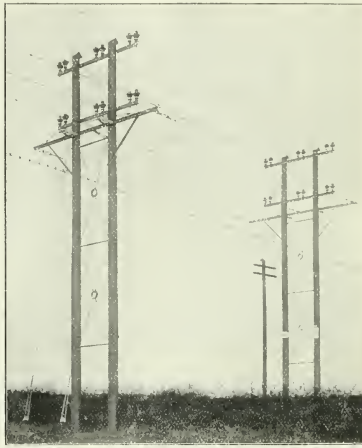

FIG. 15.—Road or Railway Guarding.

drainage coils at stated intervals along the line to remove the inductive disturbances.

When paper-insulated lead-sheathed cables are used for the telephone circuits, the much cheaper low-tension telephones of any good make may be employed, but it is advisable to protect them by heat coils, fuses, and spark-gaps. It is found that, under fault conditions on the line, the fault current partly travels through the lead sheath and sometimes induces current in the cores of the cables of sufficient magnitude to give severe shocks if the apparatus is not thus protected.

Guarding of Conductors.

With the education of the public as to the safety of overhead wires, the methods of guarding lines crossing railways and roads are becoming much simplified, resulting in reduced cost of construction and enormous gain in appearance. One important 20,000-volt line which crosses a few roads and several miles of mountain moorland much used by tourists, has been equipped throughout with earthed extension pieces of galvanized wrought iron under each insulator. The metal projects for 12 in. on each side of the insulator and the curved portion is nearly semicircular with a radius of 8 in.

The suspension guard shown in Fig. 15 finds considerable favour for road and railway crossings and is used by the Newcastle Electric Supply Company and other undertakers.

The suspender should be of the same sectional area and material as the line wire, but in the case of heavy copper line wires it is sometimes advantageous to use a stranded phosphor-bronze suspender to secure lightness. It will be seen that the suspender is anchored to the line wire at the extreme ends and is also attached to it at intermediate points ; it seems nearly impossible with this combination for a live wire to fall within reach from the ground. As a further protection, however, an earthed light cradle may be employed as shown in Fig. 15, but it does not seem to be absolutely necessary.

The triangular guard shown in Fig. 16 is a new arrangement which is due to Mr. A. P. Trotter, and has been used on the Ham line of the Twickenham & Teddington Electric Supply Company and by the Fife Power Company. It has the merits of simplicity, low cost, and ease of erection, and is likely to find considerable favour in future work.

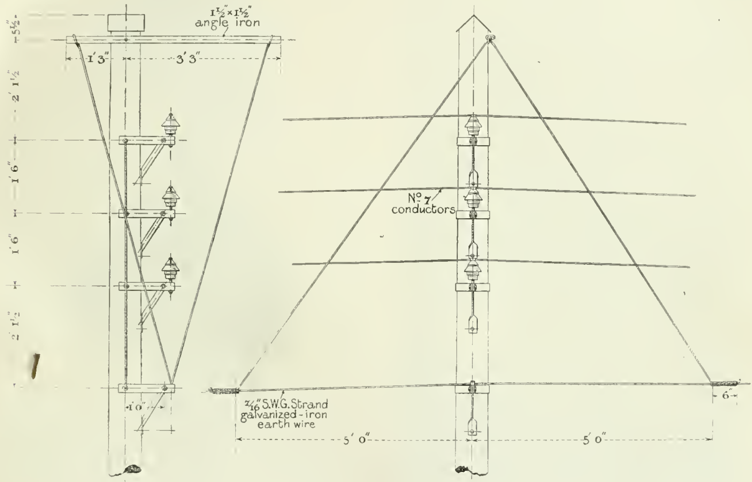

Fig. 16.—Triangular Guard.

In cases where important G.P.O. lines are met with, the department requires that bare wires working at a pressure of 3,000 volts and above shall not cross its wires, except by special arrangement, thus involving serious expense in extra terminal poles and underground high-tension cables. In some cases, the department's requirements have been met by using a joint pole for both sets of wires. A good example of this by the Cornwall Power Company is shown in Fig. 17, in which the earthed metal screen between the wires and the caging round the high-tension wires will be noticed. For pressures below 3,000 volts the high-tension conductors may be erected above the department's wires by observing certain requirements, of which particulars

can be obtained from the Engineer-in-Chief. In the case of parallel telegraph and power lines, the department requires a separating distance not less than one and a half times the height of the highest power wire or telegraph wire, whichever is greater.

With the great attention now given to the details of line construction, and with the equipment of lines with automatic protective apparatus, it is becoming exceedingly doubtful whether any guarding at all is justifiable on such lines. There is reason to believe that the line wires become "dead" within 1/80 sec. after the occurrence of a fault or short-circuit or the breakage of a wire when the Merz-Hunter split-conductor system* is employed. The Merz-Price system† will cut out the line within 1/20 sec. when an earth fault or short-circuit occurs, but it will not deal with the case of the opening of a circuit by a wire breaking until the wire becomes earthed, which may not occur until the wire has reached the ground. Considering these facts, it would seem that the time is approaching when it will be justifiable to ask for the Board of Trade's consent to run high-tension lines along public roads where the conditions are suitable, and so save the enormous amount of trouble that is involved in obtaining numerous private wayleaves.

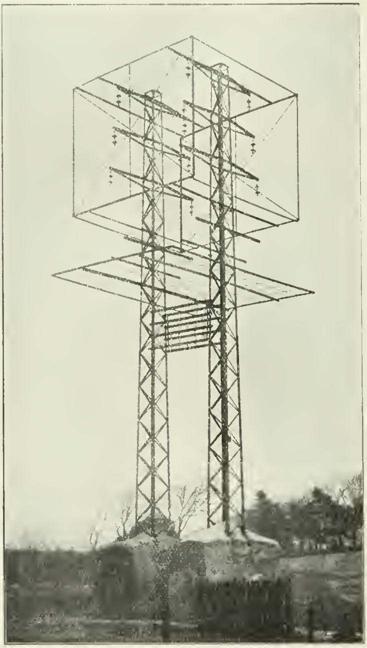

Fig. 17.—Combination Pole for High-tension Wires above and G.P.O. Wires below.

* British Patents, Nos. 4,004 and 26,857 of 1911.
† Ibid., Nos. 3,896–15,796 and 11,364 of 1904.

Cables and Terminal Boxes for Outdoor Use.

Where overhead lines cannot be connected directly to switchgear or transformers by bare conductors, the best practice is to connect up by means of paper-insulated lead-sheathed cables, built when possible to the Engineering Standards Committee's Specification. These cables are usually armoured with galvanized wire for mechanical protection and to form an additional earthed metallic shield round the cable. The armouring should be protected against corrosion, preferably by compounded tapes. Such cables are also used for bridging across gaps in a line. Experience shows that even at 20,000 volts 3-phase there is no need to make provision for protection against lightning where the cable and the line meet, and, further, that cables can be "teed" off an overhead line with safety.

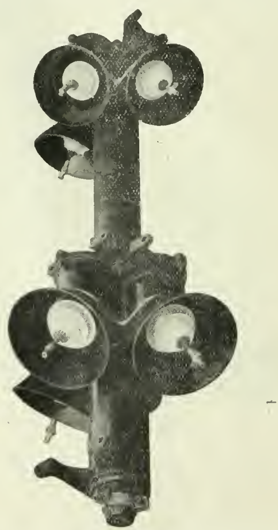

Fig. 18.—Inverted Type of Trifurcating Box arranged for Split-conductor Working.

A cast-iron box fitted with insulators is employed on a

terminal pole for sealing off the connecting cable at its junction with the line wires. Terminal boxes were very fruitful sources of breakdown until the introduction about three years ago of the inverted box in which the porcelain insulator is considerably protected from wet, snow, dirt, and mechanical damage. The author has never heard of a breakdown occurring at one of these boxes, which are obtainable for all pressures up to 20,000 volts alternat-

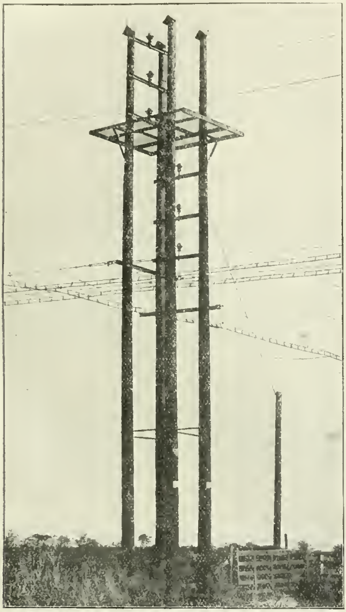

FIG. 19.—Arrangement for 20,000-volt Circuit crossing a 6,000-volt Circuit.

ing current. A patented* special form of the box for use with Merz-Hunter split conductor 20,000-volt cable is shown in Fig. 18, and is also to be seen in actual use in Fig. 6 on the terminal pole. Boxes for connecting overhead lines to cables require special design owing to the sudden change in the electrical characteristics of the circuit at the junction. The factor of safety on such a box must be at least $2\frac{1}{2}$, when tested under heavy rain conditions, in order to fulfil all requirements.

The very greatest care should be taken to ensure that all terminal boxes used out of doors should be thoroughly filled with high-grade flexible waterproof compound which will not soften appreciably under the direct rays of the sun.

It would be interesting to digress and consider for what pressure cables could be built for use with overhead lines. It can, however, be said with certainty that no pressure is likely to be employed in this country for several years to come which will not find the cable manufacturer equal to the occasion.

EXAMPLES OF SPECIAL WORK.

1. Fig. 19 shows the design of a 4-pole structure which is in use for carrying a 20,000-volt line over a 6,000-volt line. The essential feature in it is the earthed metal platform between the two sets of conductors. Such a platform should be strong enough to permit of two men standing on it simultaneously.

2. Fig. 20 illustrates a neat method of leading-in bare conductors to a station without employing insulated cables. The three horizontal insulators are made in two parts and these are mounted, as shown, on a vertical slate panel which is built into the wall.

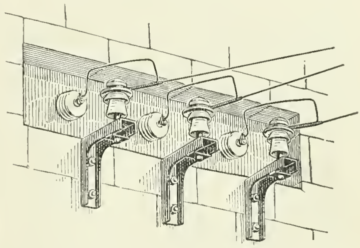

FIG. 20.—Method of Leading-in Bare Conductors to Station.

3. Attention may be called to the fact that the Board of Trade allows a supply to be given from an overhead line through a transformer fixed overhead on a pole, subject to compliance with recently issued regulations. This concession will probably be of much use when negotiations are on foot for obtaining wayleaves.

SUNDRY DETAILS.

(*a*) To prevent the climbing of poles, each separate pole should be equipped with about 10 turns of 4-barbed wire about 8 feet above ground-level, and the wire should be securely stapled to it. In a few cases *chevaux de frise* have been used.

(*b*) Each pole should have a zinc number plate (G.P.O. pattern) attached to it by zinc nails at a height of 5 ft. above the ground.

(*c*) Danger notices should be fixed on at least one pole in five, and on each pole at a road crossing.

(*d*) During erection some engineers prefer that wiremen should use ladders and not climbing irons for going up the pole. This is a wise precaution, but it must be used with discretion. Usually it is sufficient to use ladders at ter-

* Patent No. 29,783 of 1912.

minal and corner poles. In very hilly country the use of ladders may make the cost of erection altogether disproportionate to the benefit derived.

(*e*) Some engineers stipulate that the tops of poles are to be coated with a mixture of coal tar and creosote before the pole roof is fitted.

(*f*) Where game guards are required to give warning to flying birds, it is better not to use metal guards, as their swinging has been found to cause cutting of the line wires. It is equally efficient to split and fix on each wire in a span two corks 3 in. long and 1¼ in. diameter. The fixing can be done by binding the two halves of the cork with binding wire.

(*g*) During erection and during repair work line wires should always be "earthed." Where this precaution has been neglected, some cases of bad shock to linesmen have been experienced due to electrostatic charges on the wires.

(*h*) On completion of erection of a line, it is advisable to subject it to a pressure-test at twice the working pressure for ½ hour, or else to make it alive at working pressure for, say, 2 days before commencing the supply of power.

Standardization.

Transmission line designs have passed through several stages, and it would seem that lines employing wooden poles are approaching finality of design in several districts. In their reliability of operation, good mechanical construction, and general appearance, they will challenge a favourable comparison with any other lines in the world. The author suggests that the Council of this Institution might now usefully consider the appointment of a permanent Transmission Lines Committee with a view to evolving standard specifications of materials, watching and reporting on important modifications of the Regulations and practice affecting overhead lines in this and other countries, advising the Council on representations to be made to the Board of Trade, other Government Departments, the Engineering Standards Committee, etc.

In conclusion, the author wishes to express his thanks to Messrs. Merz & McLellan, Messrs. Kennedy & Jenkin, Mr. J. S. Highfield, Mr. G. K. Paton, Mr. Geo. V. Twiss, The Newcastle-upon-Tyne Electric Supply Company, Ltd., and British Insulated & Helsby Cables, Ltd., for information furnished and permission given for its publication, and to his colleagues, Messrs. J. A. Morton and James Nelson, for valuable assistance in the preparation of data and illustrations.

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Appendix I.

specification for masts.

General.—The towers are arranged with a joint immediately above the ground-level. This enables the superstructures, *i.e.* all above this joint, to be completely assembled whilst lying on the ground and then swung up into the erect position. The ground joints between the superstructure and the base legs may then be made.

Materials.—The steel used will be Siemens-Martin openhearth steel, and the sections will be straight, parallel, and free from flaws or other defects.

Rolled steel sections, bars, and plates, would have the following characteristics:—

Ultimate tensile strength	28/32 tons per. sq. in.
Minimum percentage elongation on British standard test piece	20 per cent.

Steel for nuts and bolts or rivets would have—

Ultimate tensile strength	24/28 tons per sq. in.
Minimum percentage elongation on British standard test piece.	26 per cent.

Workmanship.—Main angles will be cold sawn to dead length.

The brace angles and light material in the masts would be sheared to dead length to a jig.

The holes in the main angles and channels where necessary will be drilled to template. The holes in angles and light material would be accurately punched to template.

All parts would be carefully cut and holes accurately made so that when the members were in position the holes would come truly opposite each other before bolting up.

Design.—The masts would be designed in accordance with our standard practice and embody all the latest features.

Factor of safety.—The members would be calculated to have the factor of safety required, upon Claxton Fidler's formula and diagrams.

Wind pressure on structure.—The wind pressure is calculated upon the area of the members, full on the windward side and half on the leeward side.

Inspection.—One per cent of the masts out of the different consignments would be assembled at our works for inspecting engineer's approval as to the accurate fitting of parts.

Testing.—One of each type of mast would be erected at our works and be submitted to mechanical tests as follows :—

1. A horizontal transverse or longitudinal pull * applied at the level of the centre cross-arm.
2. A torsional couple at the centre cross-arm applied by a pull at each end and in opposite directions.
3. A vertical load applied at the end of each cross-arm.

The masts shall withstand the specified tests applied in the above manner without failure.

Packing.—The masts are made to be shipped unassembled and to be erected and assembled on site.

The material of the masts would be prepared for shipment in bundles, and so arranged that each mast would be contained in a separate set of bundles, and no bundle would contain parts other than those of the mast of which it is a component.

The complement of bolts for each mast would be packed in a separate bag, and each different size of bolt making up that complement would be placed in light separate bags within the main bag.

The fastening of the bundles would be arranged to make them as secure as possible against coming asunder in handling for shipment. The bundles would be secured with flat iron tie bars put on hot and ½ in. iron wire would be threaded through the end holes of each bundle wherever possible.

* This pull provides for the loads caused by either wind or wires (in the case of intermediate masts) or pull on the wires (in the case of the main or straining masts) as the case may be, and wind on the structure.

Erection marks.—Each piece or member in the mast would be marked with an erection number corresponding to the numbers on the erection drawings.

Erection drawings.—The necessary quantity of erection drawings would be supplied.

Guarantee.—We guarantee the masts as being scientifically and correctly designed to withstand the calculated loads, and that they would be made of the best material for the purpose and the highest class of workmanship.

Weights.—The weights of the masts given are dependent upon the usual permissible rolling margin of 3 per cent up and down.

Painting.—The material of the masts would be brushed with steel brushes, and specially treated with a continuous covering of bitumastic solution applied before leaving the works.

Nuts and bolts.—The nuts and bolts would be supplied to Whitworth standards and arranged to give good fitting in the holes and so that the unthreaded portion only comes through the holes.

Spares.—The quantity of nuts and bolts would include an allowance of 5 per cent for spares.

Danger plates.—Danger or warning plates for the masts, unless otherwise stated, are not included.

Insulator fixings and earth-wire clamps.—Unless otherwise stated, clamps for fixing lightning wires or clevises for fixing suspension insulators to the masts are not included.

Climbing irons.—In cases where the bracings of the masts are placed close together a man can scale up these, and therefore climbing irons are not included. In cases, however, where the bracings are not sufficiently close together to be readily scaled, then the necessary number of climbing irons are included.

APPENDIX II.

FORMULÆ FOR FINDING SAFE DIP OF LINE WIRES, TAKING INTO ACCOUNT WIND PRESSURE.

$$(1)\ d = \frac{l^2 w}{8 s} \quad (2)\ d_1 = \sqrt{d^2 + l^2(\mathrm{T} \times \tfrac{3}{8} k)},$$

where l = length of span in feet,

d = dip in feet at minimum temperature (22° F. in England),

d_1 = dip in feet at maximum temperature (75° F. in England),

s = stress at minimum temperature in lb. = breaking stress of wire in lb. ÷ factor of safety,

$w = \sqrt{\mathrm{W}^2 + \mathrm{P}^2}$,

W = weight of wire in lb. per foot,

P = 0·050 × wind pressure in lb. per sq. ft. × diameter of wire in inches,

T = difference in degrees F. between minimum and higher temperature,

k = coefficient of expansion per degree F. (0·0000093 for copper and 0·0000136 for aluminium).

Where T = 53° F. then $(\mathrm{T} \times \tfrac{3}{8} k)$ = 0·000174 for copper, 0·00027 for aluminium, and 0·0001214 for steel.

(No allowance need be made for the possible accumulation of ice or snow.)

Appendix III.

Nominal Area in sq. in.	S.W.G. Size of Copper Line Wire	Resistance in ohms at 60° F. Per Mile of Line	Per 1 000 yards of Line	Ratio of Reactance to Resistance for certain Distances between the Wires and at certain Periodicities: 12 inches 25 ∼	12 inches 40 ∼	12 inches 50 ∼	12 inches 60 ∼	18 inches 25 ∼	18 inches 40 ∼	18 inches 50 ∼	18 inches 60 ∼	24 inches 25 ∼	24 inches 40 ∼	24 inches 50 ∼	24 inches 60 ∼
0·0032	16	26·83	15·245	0·0233	0·0372	0·0465	0·0558	0·0248	0·0397	0·0495	0·0596	0·0259	0·0414	0·0517	0·0621
0·005	14	17·173	9·757	0·0351	0·056	0·0701	0·0842	0·0374	0·0599	0·0748	0·0899	0·0391	0·0625	0·0782	0·0939
0·0085	12	10·162	5·773	0·0566	0·0906	0·113	0·136	0·0606	0·097	0·121	0·146	0·0635	0·1015	0·127	0·152
0·0128	10	6·709	3·812	0·0827	0·132	0·165	0·198	0·0888	0·142	0·177	0·213	0·093	0·149	0·186	0·223
0·0163	9	5·3	3·011	0·102	0·1637	0·204	0·245	0·11	0·176	0·22	0·264	0·1156	0·185	0·231	0·278
0·0201	8	4·292	2·438	0·124	0·198	0·248	0·297	0·133	0·213	0·267	0·32	0·14	0·224	0·281	0·337
0·0243	7	3·548	2·016	0·147	0·236	0·294	0·353	0·159	0·254	0·318	0·381	0·167	0·267	0·333	0·4
0·0289	6	2·982	1·694	0·172	0·276	0·344	0·413	0·186	0·297	0·371	0·446	0·196	0·313	0·391	0·47
0·0353	5	2·446	1·39	0·206	0·329	0·412	0·494	0·222	0·356	0·445	0·534	0·234	0·375	0·469	0·563
0·0422	4	2·042	1·16	0·242	0·387	0·484	0·581	0·262	0·42	0·524	0·629	0·276	0·442	0·552	0·664
0·0498	3	1·731	0·983	0·281	0·45	0·562	0·674	0·304	0·487	0·608	0·731	0·321	0·514	0·642	0·771
0·0598	2	1·443	0·82	0·33	0·528	0·661	0·793	0·358	0·573	0·717	0·861	0·379	0·606	0·757	0·91
0·0707	1	1·222	0·694	0·384	0·614	0·766	0·92	0·417	0·667	0·833	1·0	0·44	0·704	0·88	1·057
0·0824	1/0	1·047	0·595	0·44	0·703	0·88	1·055	0·479	0·766	0·958	1·15	0·506	0·81	1·012	1·215
0·0951	2/0	0·908	0·516	0·498	0·798	0·996	1·198	0·544	0·87	1·087	1·306	0·576	0·922	1·151	1·382
0·1087	3/0	0·794	0·451	0·562	0·9	1·124	1·35	0·614	0·982	1·226	1·472	0·65	1·042	1·302	1·561
0·1257	4/0	0·687	0·39	0·639	1·023	1·28	1·535	0·699	1·118	1·398	1·677	0·742	1·187	1·482	1·78
0·15	19/0·101	0·5781	0·3284	0·718	1·151	1·437	1·727	0·789	1·263	1·577	1·894	0·84	1·345	1·68	2·02
0·2	37/0·083	0·4395	0·2497	0·914	1·466	1·827	2·19	1·007	1·612	2·02	2·42	1·073	1·72	2·15	2·58
0·25	37/0·092	0·358	0·2034	1·091	1·745	2·18	2·62	1·205	1·932	2·41	2·89	1·286	2·06	2·57	3·09
0·3	37/0·104	0·2801	0·1591	1·353	2·16	2·7	3·25	1·497	2·4	2·99	—	1·602	2·57	3·2	—
0·4	37/0·118	0·2176	0·1236	1·68	2·69	3·36	—	1·87	2·99		—	2·0	3·2	—	—
0·5	61/0·104	0·1698	0·0965	2·08	3·33	—		2·32	—	—	—	2·49	—	—	

Nominal Area in sq. in.	S.W.G. Size of Copper Line Wire	Resistance in ohms at 60° F. Per Mile of Line	Per 1,000 yards of Line	Ratio of Reactance to Resistance for certain Distances between the Wires and at certain Periodicities: 30 inches 25 ∼	30 inches 40 ∼	30 inches 50 ∼	30 inches 60 ∼	36 inches 25 ∼	36 inches 40 ∼	36 inches 50 ∼	36 inches 60 ∼	42 inches 25 ∼	42 inches 40 ∼	42 inches 50 ∼	42 inches 60 ∼
0·0032	16	26·83	15·245	0·0267	0·0428	0·0534	0·0641	0·0274	0·0438	0·0548	0·0658	0·028	0·0447	0·056	0·0672
0·005	14	17·173	9·757	0·0404	0·0647	0·0808	0·097	0·0415	0·0664	0·083	0·0996	0·0424	0·0678	0·0849	0·1018
0·0085	12	10·162	5·773	0·0658	0·105	0·131	0·158	0·0675	0·108	0·135	0·145	0·0691	0·11	0·138	0·166
0·0128	10	6·709	3·812	0·0964	0·154	0·193	0·232	0·0992	0·159	0·198	0·238	0·1015	0·162	0·203	0·244
0·0163	9	5·3	3·011	0·12	0·192	0·24	0·288	0·123	0·197	0·246	0·296	0·126	0·202	0·252	0·303
0·0201	8	4·292	2·438	0·145	0·233	0·291	0·349	0·15	0·24	0·3	0·36	0·153	0·245	0·307	0·368
0·0243	7	3·548	2·016	0·173	0·277	0·346	0·416	0·178	0·285	0·357	0·428	0·183	0·292	0·365	0·439
0·0289	6	2·982	1·694	0·203	0·325	0·406	0·487	0·209	0·335	0·418	0·502	0·215	0·343	0·429	0·515
0·0353	5	2·446	1·39	0·244	0·39	0·487	0·585	0·251	0·402	0·502	0·603	0·258	0·412	0·514	0·618
0·0422	4	2·042	1·16	0.288	0·46	0·574	0·69	0·297	0·474	0·593	0·712	0·304	0·486	0·608	0·73
0·0498	3	1·731	0·983	0·334	0·535	0·668	0·802	0·345	0·552	0·69	0·828	0·354	0·567	0·708	0·85
0·0598	2	1·443	0·82	0·395	0·63	0·789	0·948	0·407	0·651	0·814	0·977	0·418	0·668	0·835	1·002
0·0707	1	1·222	0·694	0·459	0·735	0·918	1·103	0·473	0·76	0·948	1·138	0·487	0·778	0·974	1·168
0·0824	1/0	1·047	0·595	0·528	0·845	1·056	1·267	0·546	0·874	1·092	1·311	0·56	0·896	1·12	1·344
0·0951	2/0	0·908	0·516	0·6	0·961	1·201	1·442	0·621	0·994	1·242	1·492	0·638	1·021	1·275	1·533
0·1087	3/0	0·794	0·451	0·679	1·086	1·357	1·63	0·702	1·124	1·404	1·685	0·723	1·155	1·444	1·734
0·1257	4/0	0·687	0·39	0·774	1·238	1·549	1·856	0·801	1·282	1·603	1·923	0·824	1·318	1·646	1·98
0·15	19/0·101	0·5781	0·3284	0·879	1·406	1·757	2·11	0·911	1·458	1·82	2·19	0·938	1·5	1·875	2·25
0·2	37/0·083	0·4395	0·2497	1·124	1·8	2·25	2·7	1·167	1·867	2·33	2·79	1·202	1·923	2·4	2·89
0·25	37/0·092	0·358	0·2034	1·35	2·16	2·7	3·24	1·402	2·24	2·8	3·37	1·445	2·31	2·89	3·47
0·3	37/0·104	0·2801	0·1591	1·683	2·69	3·36	—	1·75	2·8	3·5	—	1·805	2·89	—	—
0·4	37/0·118	0·2176	0·1236	2·11	3·37	—	—	2·19	3·5	—	—	2·26	—	—	—
0·5	61/0·104	0·1698	0·0965	2·62	—	—	—	2·73	—	—	—	2·82	—	—	—

APPENDIX III—*Continued.*

Nominal Area in sq. in.	S.W.G. Size of Copper Line Wire	Resistance in ohms at 60° F. Per Mile of Line	Per 1,000 yards of Line	Ratio of Reactance to Resistance for certain Distances between the Wires and at certain Periodicities: 48 inches 25 ∼	48 inches 40 ∼	48 inches 50 ∼	48 inches 60 ∼	60 inches 25 ∼	60 inches 40 ∼	60 inches 50 ∼	60 inches 60 ∼	72 inches 25 ∼	72 inches 40 ∼	72 inches 50 ∼	72 inches 60 ∼
0·0032	16	26·83	15·245	0·0285	0·0456	0·0569	0·0683	0·0293	0·0469	0·0586	0·0704	0·03	0·048	0·06	0·072
0·005	14	17·173	9·757	0·0432	0·0691	0·0863	0·1036	0·0445	0·0712	0·089	0·1067	0·0456	0·0729	0·0911	0·1095
0·0085	12	10·162	5·773	0·0704	0·113	0·141	0·169	0·0724	0·116	0·145	0·175	0·0744	0·119	0·140	0·179
0·0128	10	6·709	3·812	0·1035	0·166	0·207	0·249	0·107	0·172	0·214	0·257	0·1096	0·175	0·219	0·263
0·0163	9	5·3	3·011	0·129	0·206	0·257	0·309	0·133	0·213	0·266	0·319	0·136	0·219	0·273	0·328
0·0201	8	4·292	2·438	0·156	0·251	0·313	0·376	0·162	0·259	0·324	0·388	0·166	0·266	0·332	0·399
0·0243	7	3·548	2·016	0·187	0·299	0·373	0·449	0·193	0·309	0·386	0·463	0·198	0·317	0·396	0·476
0·0289	6	2·982	1·694	0·219	0·351	0·438	0·526	0·227	0·362	0·453	0·544	0·233	0·372	0·465	0·559
0·0353	5	2·446	1·39	0·263	0·421	0·526	0·632	0·272	0·435	0·545	0·653	0·28	0·448	0·56	0·672
0·0422	4	2·042	1·16	0·31	0·406	0·62	0·746	0·322	0·515	0·643	0·772	0·331	0·529	0·661	0·794
0·0498	3	1·731	0·983	0·362	0·579	0·722	0·868	0·375	0·599	0·749	0·9	0·385	0·610	0·77	0·925
0·0598	2	1·443	0·82	0·427	0·683	0·854	1·026	0·443	0·708	0·885	1·064	0·456	0·729	0·911	1·094
0·0707	1	1·222	0·694	0·498	0·796	0·996	1·195	0·516	0·826	1·032	1·24	0·532	0·85	1·062	1·277
0·0824	1/0	1·047	0·595	0·573	0·917	1·146	1·377	0·595	0·951	1·19	1·428	0·612	0·98	1·224	1·47
0·0951	2/0	0·908	0·516	0·653	1·045	1·304	1·568	0·678	1·085	1·356	1·628	0·698	1·116	1·395	1·676
0·1087	3/0	0·794	0·451	0·74	1·182	1·477	1·773	0·767	1·226	1·534	1·843	0·79	1·264	1·58	1·898
0·1257	4/0	0·687	0·39	0·842	1·352	1·687	2·03	0·877	1·403	1·754	2·11	0·904	1·446	1·805	2·17
0·15	19/0·101	0·5781	0·3284	0·961	1·537	1·92	2·31	1·0	1·598	2·0	2·4	1·032	1·65	2·06	2·48
0·2	37/0·083	0·4395	0·2497	1·232	1·972	2·46	2·96	1·283	2·06	2·56	3·08	1·325	2·12	2·65	3·18
0·25	37/0·092	0·358	0·2034	1·482	2·37	2·96	3·56	1·545	2·47	3·09	—	1·597	2·55	3·19	—
0·3	37/0·104	0·2801	0·1591	1·852	2·97	—	—	1·933	3·09	—	—	2·0	3·2	—	—
0·4	37/0·118	0·2176	0·1236	2·32	—	—	—	2·43	—	—	—	2·51	—	—	—
0·5	61/0·104	0·1698	0·0965	2·9	—	—	—	3·04	—	—	—	3·14	—	—	—

Nominal Area in sq. in.	S.W.G. Size of Copper Line Wire	Resistance in ohms at 60° F. Per Mile of Line	Per 1,000 yards of Line	Ratio of Reactance to Resistance for certain Distances between the Wires and at certain Periodicities: 84 inches 25 ∼	84 inches 40 ∼	84 inches 50 ∼	84 inches 60 ∼	90 inches 25 ∼	90 inches 40 ∼	90 inches 50 ∼	90 inches 60 ∼
0·0032	16	26·83	15·245	0·0306	0·0489	0·0611	0·0735	0·0309	0·0494	0·0617	0·0741
0·005	14	17·173	9·757	0·0465	0·0744	0·093	0·1116	0·0469	0·075	0·0938	0·1125
0·0085	12	10·162	5·773	0·0759	0·121	0·152	0·182	0·0766	0·123	0·153	0·184
0·0128	10	6·709	3·812	0·112	0·179	0·224	0·269	0·113	0·181	0·226	0·271
0·0163	9	5·3	3·011	0·14	0·223	0·279	0·335	0·141	0·225	0·282	0·338
0·0201	8	4·292	2·438	0·17	0·272	0·34	0·408	0·171	0·274	0·343	0·412
0·0243	7	3·548	2·016	0·203	0·324	0·405	0·486	0·205	0·328	0·409	0·491
0·0289	6	2·982	1·694	0·238	0·381	0·476	0·571	0·24	0·385	0·48	0·577
0·0353	5	2·446	1·39	0·286	0·458	0·572	0·686	0·289	0·462	0·578	0·693
0·0422	4	2·042	1·16	0·338	0·541	0·677	0·813	0·342	0·546	0·683	0·821
0·0498	3	1·731	0·983	0·394	0·631	0·788	0·947	0·398	0·638	0·796	0·956
0·0598	2	1·443	0·82	0·467	0·746	0·933	1·12	0·471	0·754	0·943	1·132
0·0707	1	1·222	0·694	0·544	0·87	1·088	1·307	0·55	0·88	1·1	1·32
0·0824	1/0	1·047	0·595	0·628	1·003	1·254	1·506	0·633	1·014	1·267	1·52
0·0951	2/0	0·908	0·516	0·716	1·143	1·43	1·717	0·723	1·157	1·445	1·736
0·1087	3/0	0·794	0·451	0·81	1·295	1·618	1·945	0·819	1·31	1·636	1·967
0·1257	4/0	0·687	0·39	0·926	1·482	1·851	2·22	0·936	1·497	1·872	2·25
0·15	19/0·101	0·5781	0·3284	1·06	1·696	2·12	2·55	1·07	1·714	2·14	2·57
0·2	37/0·083	0·4395	0·2497	1·362	2·18	2·72	3·27	1·377	2·2	2·75	3·31
0·25	37/0·092	0·358	0·2034	1·642	2·62	3·28	—	1·662	2·65	3·32	—
0·3	37/0·104	0·2801	0·1591	2·05	3·29	—	—	2·08	3·33	—	—
0·4	37/0·118	0·2176	0·1236	2·58	—	—	—	2·62	—	—	—
0·5	61/0·104	0·1698	0·0965	3·24	—	—	—	3·28	—	—	—

NOTES.—(*a*) The resistance is given per 1,000 yards of 2-wire circuit, *i.e.* the actual length of wire is 2,000 yards. The resistances given are for hard-drawn copper wire.

(*b*) In 3-phase 3-wire circuits the conductors are supposed to be spaced at the corners of an equilateral triangle with the distance between corners as given above.

(*c*) From this Table can be found the ohmic value of self-induction (reactance) per 1,000 yards of a 2-wire circuit —resistance × ratio.

(*d*) The self-induction in millihenries per 1,000 yards of a 2-wire circuit $= \dfrac{\text{resistance} \times \text{ratio} \times 1000}{2\pi \times \text{periodicity}}$.

Appendix IV.

VOLTAGE LOSS IN ALTERNATING-CURRENT OVERHEAD CIRCUITS.

Drop-factors when voltage lost in resistance is 10 per cent of the delivered voltage.

Ratio of Reactance to Resistance	Drop-factors for Power Factors of						
	1·0	0·95	0·9	0·85	0·8	0·7	0·6
0·1	1·00	0·98	0·95	0·912	0·872	0·79	0·706
0·2	1·002	1·012	0·99	0·962	0·93	0·86	0·782
0·3	1·004	1·044	1·032	1·012	0·986	0·925	0·862
0·4	1·007	1·075	1·075	1·062	1·042	0·995	0·942
0·5	1·01	1·11	1·118	1·114	1·102	1·062	1·022
0·6	1·014	1·14	1·165	1·165	1·16	1·13	1·1
0·7	1·02	1·174	1·21	1·22	1·22	1·195	1·172
0·8	1·028	1·21	1·255	1·27	1·28	1·263	1·25
0·9	1·035	1·243	1·3	1·325	1·34	1·332	1·325
1·0	1·045	1·28	1·345	1·38	1·401	1·402	1·401
1·1	1·053	1·317	1·392	1·433	1·462	1·472	1·48
1·2	1·063	1·353	1·44	1·49	1·525	1·546	1·56
1·3	1·075	1·392	1·49	1·545	1·59	1·62	1·64
1·4	1·088	1·43	1·54	1·6	1·65	1·7	1·72
1·5	1·1	1·472	1·59	1·663	1·716	1·775	1·8
1·6	1·118	1·514	1·64	1·72	1·78	1·85	1·88
1·7	1·13	1·555	1·69	1·78	1·84	1·925	1·96
1·8	1·147	1·6	1·74	1·84	1·91	2·0	2·042
1·9	1·163	1·642	1·795	1·9	1·974	2·073	2·123
2·0	1·18	1·684	1·85	1·96	2·04	2·15	2·207
2·1	1·198	1·73	1·9	2·02	2·11	2·227	2·29
2·2	1·215	1·77	1·96	2·08	2·175	2·3	2·37
2·3	1·234	1·82	2·01	2·14	2·24	2·38	2·453
2·4	1·254	1·86	2·07	2·205	2·31	2·455	2·537
2·5	1·275	1·91	2·125	2·27	2·38	2·53	2·62
2·6	1·3	1·96	2·18	2·33	2·45	2·605	2·7
2·7	1·322	2·005	2·24	2·4	2·52	2·68	2·785
2·8	1·348	2·05	2·295	2·46	2·585	2·76	2·87
2·9	1·373	2·1	2·355	2·53	2·66	2·84	2·955
3·0	1·4	2·155	2·416	2·595	2·728	2·918	3·04
3·5	1·56	2·44	2·72	2·93	3·08	3·32	3·46

Appendix V.

TABLE OF SAFE CURRENTS FOR OVERHEAD WIRES.

Currents which give a maximum temperature rise of 50° and 100° Fahr. in still air, with bare hard-drawn copper wires.

Size, S.W.G.	Area in sq. in.	Current for Temp. Rise		Size, S.W.G.	Area in sq. in.	Current for Temp. Rise	
		50°	100°			50°	100°
		Amps.	Amps.			Amps.	Amps.
16	0·0032	13½	18½	3/0	0·1087	190	261
14	0·0050	19	26	4/0	0·1257	212	291
12	0·0085	28	38½	19/0·101	0·150	267	360
10	0·0128	38	52½	37/0·083	0·200	330	445
8	0·0201	53½	73½	37/0·092	0·250	389	524
7	0·0243	62	85	37/0·104	0·300	446	602
6	0·0289	70½	96	37/0·118	0·400	555	746
5	0·0353	81½	112	61/0·104	0·500	654	882
4	0·0423	93½	129	61/0·112	0·600	753	1,016
3	0·0499	106	145	91/0·101	0·750	888	1,198
2	0·0598	121	166	91/0·108	0·800	931	1,256
1	0·0707	137½	189	91/0·112	0·900	1,018	1,372
1/0	0·0824	154½	212	91/0·118	1·000	1,100	1,486
2/0	0·0951	172	236				

Note.—An aluminium cable will carry 14 per cent more current for the same temperature rise than a copper one of equal resistance, but the voltage drop will necessarily be greater.

Appendix VI.

Capacity (Electrostatic) in Overhead Bare Copper Conductors.

The following Table gives the capacity, in microfarads per 1,000 *yards of line in a* 2-*wire circuit, of different sizes of conductors with various spacings between them. In the case of a* 3-*phase circuit there are practically three equal capacities, as was shown in Fig.* 4, *and* C_1 *will equal twice the figure given in the Table.*

Nominal area in sq. in.	Size of Conductor	Distance between Centres of Conductors in inches: 6	12	18	24	30	36	42	48	60	72	84	90
0·0032	16 S.W.G.	0·00485	0·00428	0·00401	0·00383	0·00371	0·00361	0·00354	0·00347	0·00337	0·00329	0·00322	0·0032
0·005	14 „	0·00507	0·00445	0·00415	0·00396	0·00383	0·00373	0·00365	0·00358	0·00347	0·00339	0·00332	0·00329
0·0085	12 „	0·00534	0·00466	0·00434	0·00414	0·00399	0·00388	0·00379	0·00372	0·0036	0·00351	0·00344	0·00341
0·0128	10 „	0·00559	0·00485	0·0045	0·00428	0·00413	0·00401	0·00392	0·00383	0·00371	0·00361	0·00354	0·0035
0·0163	9 „	0·00574	0·00496	0·0046	0·00437	0·00421	0·00408	0·00399	0·0039	0·00376	0·00367	0·0036	0·00356
0·0201	8 „	0·00588	0·00507	0·00469	0·00445	0·00428	0·00415	0·00405	0·00396	0·00383	0·00373	0·00365	0·00361
0·0243	7 „	0·00601	0·00516	0·00477	0·00452	0·00435	0·00422	0·00412	0·00403	0·00389	0·00378	0·0037	0·00366
0·0289	6 „	0·00614	0·00526	0·00485	0·0046	0·00442	0·00428	0·00417	0·00408	0·00394	0·00383	0·00375	0·00371
0·0353	5 „	0·00629	0·00536	0·00494	0·00468	0·0045	0·00436	0·00424	0·00415	0·004	0·00389	0·0038	0·00376
0·0422	4 „	0·00643	0·00547	0·00503	0·00476	0·00457	0·00442	0·00431	0·00421	0·00406	0·00395	0·00385	0·00382
0·0498	3 „	0·00657	0·00557	0·00512	0·00484	0·00464	0·00449	0·00437	0·00427	0·00412	0·004	0·0039	0·00386
0·0598	2 „	0·00673	0·00568	0·00521	0·00492	0·00472	0·00456	0·00444	0·00434	0·00418	0·00406	0·00396	0·00392
0·0707	1 „	0·00688	0·00579	0·0053	0·005	0·00479	0·00463	0·00451	0·0044	0·00424	0·00411	0·00401	0·00397
0·0824	1/0 „	0·00703	0·0059	0·00539	0·00508	0·00486	0·0047	0·00457	0·00446	0·00429	0·00416	0·00405	0·00402
0·0951	2/0 „	0·00717	0·006	0·00547	0·00515	0·00493	0·00476	0·00463	0·00452	0·00435	0·00421	0·00411	0·00406
0·1087	3/0 „	0·0073	0·00609	0·00555	0·00522	0·005	0·00482	0·00468	0·00457	0·0044	0·00426	0·00415	0·00411
0·1257	4/0 „	0·00746	0·0062	0·00564	0·0053	0·00507	0·00489	0·00475	0·00463	0·00445	0·0043	0·0042	0·00415
0·15	19/0·101 in.	0·00802	0·00657	0·00595	0·00557	0·00531	0·00512	0·00496	0·00481	0·00464	0·00449	0·00437	0·00432
0·2	37/0·083 „	0·00838	0·00682	0·00615	0·00575	0·00547	0·00526	0·0051	0·00497	0·00476	0·0046	0·00448	0·00442
0·25	37/0·092 „	0·00868	0·00702	0·00631	0·00588	0·0056	0·00538	0·00521	0·00507	0·00485	0·00469	0·00456	0·00451
0·3	37/0·104 „	0·00906	0·00726	0·00651	0·00606	0·00575	0·00552	0·00534	0·0052	0·00497	0·0048	0·00466	0·00461
0·4	37/0·118 „	0·00948	0·00753	0·00672	0·00625	0·00592	0·00568	0·00549	0·00534	0·00509	0·00492	0·00478	0·00472
0·5	61/0·104 „	0·00995	0·00782	0·00695	0·00645	0·0061	0·00585	0·00564	0·00548	0·00523	0·00504	0·00489	0·00482
0·6	61/0·112 „	0·01024	0·008	0·0071	0·00657	0·00621	0·00594	0·00574	0·00557	0·00531	0·00511	0·00496	0·00489
0·75	91/0·101 „	0·01066	0·00826	0·00729	0·00674	0·00636	0·00608	0·00586	0·00569	0·00541	0·00521	0·00506	0·00499
1·00	91/0·118 „	0·01141	0·0087	0·00764	0·00702	0·00662	0·00632	0·00609	0·00589	0·0056	0·0053	0·00522	0·00514

Appendix VII.

Overhead Transmission Lines. Capacity (Electrostatic) of Bare Aluminium Conductors.

The following Table gives the capacity, in microfarads per 1,000 *yards of line in a* 2-*wire circuit, of different sizes of conductors with various spacings between them. In the case of a* 3-*phase circuit there are practically three equal capacities, as was shown in Fig.* 4, *and* C_1 *will equal twice the figure given in the Table.*

Copper Conductors: Nomioal Area in square inches	Copper Conductors: Size of Conductor	Aluminium Conductors of equal Conductivity	Distance between Centres of Conductors in inches: 6	12	18	24	30	36	42	48	60	72	84	90
0·0032	16 S.W.G.	1 0·083 in.	0·0051	0·00448	0·00418	0·00399	0·00386	0·00375	0·00367	0·0036	0·00349	0·0034	0·00334	0·00328
0·004	15 „	1/0·093 „	0·00522	0·00457	0·00426	0·00406	0·00392	0·00382	0·00373	0·00366	0·00355	0·00346	0·00339	0·00336
0·005	14 „	1/0·103 „	0·00534	0·00466	0·00433	0·00413	0·00399	0·00387	0·00379	0·00371	0·0036	0·00351	0·00343	0·0034
0·0066	13 „	1 0·119 „	0·0055	0·00478	0·00444	0·00423	0·00408	0·00396	0·00387	0·0038	0·00367	0·00358	0·0035	0·00347
0·0085	12 „	1/0·135 „	0·00565	0·0049	0·00455	0·00432	0·00416	0·00405	0·00395	0·00387	0·00374	0·00364	0·00356	0·00353
0·0105	11 „	7/0·057 „	0·00597	0·00514	0·00474	0·0045	0·00433	0·0042	0·0041	0·00401	0·00387	0·00377	0·00369	0·00365
0·0128	10 „	7/0·063 „	0·00612	0·00524	0·00484	0·00458	0·00441	0·00427	0·00417	0·00408	0·00393	0·00383	0·00374	0·0037
0·0163	9 „	7/0·071 „	0·0063	0·00537	0·00495	0·00468	0·0045	0·00436	0·00425	0·00415	0·00401	0·0039	0·00381	0·00377
0·0201	8 „	7/0·079 „	0·00647	0·0055	0·00505	0·00478	0·00459	0·00444	0·00432	0·00423	0·00408	0·00396	0·00387	0·00383
0·0243	7 „	7/0·087 „	0·00663	0·00562	0·00515	0·00487	0·00467	0·00452	0·0044	0·0043	0·00414	0·00402	0·00393	0·00389
0·0289	6 „	7/0·095 „	0·00679	0·00573	0·00525	0·00495	0·00474	0·00459	0·00446	0·00437	0·0042	0·00408	0·00398	0·00394
0·0353	5 „	7/0·105 „	0·00698	0·00586	0·00536	0·00505	0·00484	0·00467	0·00454	0·00444	0·00427	0·00415	0·00405	0·004
0·0422	4 „	7/0·115 „	0·00715	0·00598	0·00546	0·00514	0·00492	0·00475	0·00462	0·00451	0·00434	0·00421	0·0041	0·00406
0·0499	3 „	7/0·124 „	0·0073	0·00609	0·00555	0·00522	0·00499	0·00482	0·00468	0·00457	0·0044	0·00426	0·00415	0·00411
0·0598	2 „	7/0·136 „	0·00751	0·00623	0·00567	0·00532	0·00509	0·00491	0·00476	0·00465	0·00447	0·00433	0·00422	0·00417
0·0707	1 „	7/0·148 „	0·0077	0·00636	0·00577	0·00542	0·00517	0·00499	0·00484	0·00472	0·00453	0·00439	0·00428	0·00423
0·0824	1/0 „	7/0·160 „	0·00789	0·00649	0·00588	0·00551	0·00526	0·00507	0·00491	0·00479	0·0046	0·00445	0·00433	0·00428
0·0951	2/0 „	7/0·172 „	0·00807	0·00661	0·00598	0·0056	0·00534	0·00514	0·00499	0·00486	0·00466	0·00451	0·00439	0·00434
0·1087	3/0 „	7/0·183 „	0·00823	0·00672	0·00607	0·00568	0·00541	0·00521	0·00504	0·00491	0·00471	0·00456	0·00444	0·00438
0·1257	4/0 „	7/0·197 „	0·00843	0·00685	0·00618	0·00577	0·0055	0·00529	0·00512	0·00499	0·00478	0·00462	0·00449	0·00444
0·15	19/0·101 in.	7/0·216 „	0·0087	0·00703	0·00632	0·0059	0·00561	0·00539	0·00522	0·00508	0·00486	0·0047	0·00457	0·00451
0·20	37/0·083 „	19/0·151 „	0·00918	0·00734	0·00657	0·00611	0·0058	0·00557	0·00539	0·00524	0·00501	0·00484	0·0047	0·00464
0·25	37/0·092 „	19/0·169 „	0·00957	0·00759	0·00677	0·00628	0·00596	0·00571	0·00552	0·00536	0·00512	0·00494	0·0048	0·00474
0·30	37/0·104 „	19/0·185 „	0·00991	0·0078	0·00693	0·00643	0·00609	0·00583	0·00563	0·00547	0·00522	0·00503	0·00488	0·00482
0·40	37/0·118 „	19/0·214 „	0·0105	0·00816	0·00722	0·00667	0·0063	0·00603	0·00582	0·00564	0·00538	0·00518	0·00502	0·00495
0·50	61/0·104 „	37/0·171 „	0·01101	0·00846	0·00746	0·00688	0·00648	0·00619	0·00597	0·00579	0·00551	0·0053	0·00514	0·00507
0·60	61/0·112 „	37/0·188 „	0·01148	0·00874	0·00767	0·00706	0·00664	0·00634	0·00611	0·00592	0·00562	0·00541	0·00524	0·00516
0·75	91/0·101 „	37/0·210 „	0·01209	0·00909	0·00793	0·00728	0·00684	0·00652	0·00628	0·00607	0·00577	0·00554	0·00536	0·00528
1·00	91/0·118 „	37/0·242 „	0·01296	0·00958	0·0083	0·00759	0·00711	0·00677	0·0065	0·0062	0·00596	0·00571	0·00552	0·00544

Appendix VIII.

COMPARISON OF THE PHYSICAL, MECHANICAL, AND ELECTRICAL PROPERTIES OF ALUMINIUM AND COPPER.

Property		Aluminium	Copper
Electric conductivity (silver = 100) ...		58·5	97·5
Coefficient of linear expansion per degree C....		0·000245	0·0000167
Coefficient of linear expansion per degree F. ...		0·000136	0·0000093
Specific gravity, cast ingots ...		2·706	8·78
Specific gravity, rolled or drawn ...		2·71	8·95
Tensile strength in lb. per sq. in. No. 4–No. 16 S.W.G. ...		24,600–33,000	55,700–62,500
Tensile strength in kg. per sq. mm. ...		17–23	38–44
Elastic limit (limit of proportionality) as per cent of tensile strength ...		70	75
Modulus of elasticity, in lb. per sq. in....		9,800,000	16,000,000
Modulus of elasticity, in kg. per sq. mm. ...		6,905	11,200
Specific resistance, in microhms per cub. cm. at 60° F. (15·5° C.)	soft	2·827	1·696
	hard	2·884	1·730
Specific resistance, in microhms per cub. cm. at 0° C. (32° F.) ...	soft	2·667	1·600
	hard	2·768	1·660
Resistance of conductor 1,000 yards long by 1 sq. in. in cross-section	soft	0·04008	0·02404
	hard	0·04089	0·02453
Coefficient of increase of resistance with temperature ...	per deg. C.	0·0032–0·0040	0·0038–0·0043
	per deg. F.	0·0018–0·0022	0·0021–0·0024
Weight per 1,000 yards by 1 sq. in. nominal section, in lb. ...		3.520	11,700
Weight per 100 feet by 1 sq. in. nominal section, in lb. ...		117·3	392

Appendix IX.

LIST OF THE STRANDS RECOMMENDED FOR HARD-DRAWN COPPER AND ALUMINIUM CONDUCTORS FOR USE ON OVERHEAD LINES.

Actual Effective Area	Copper		Equivalent Aluminium for Equal Resistance	
	Strand	Approx. Weight per Mile	Strand	Approx. Weight per Mile
Sq. in.	S.W.G.	lb.	S.W.G.	lb.
0·025	7/0·068	530	7/0·088	267
0·05	7/0·096	1,056	7/0·124	532
0·075	7/0·118	1,585	7/0·152	798
0·10	7/0·136	2,110	7/0·176	1,070
0·15	7/0·167	3,180	12/0·164	1,600
0·20	7/0·192	4,200	19/0·151	2,145
0·25	7/0·215	5,275	19/0·169	2,665
0·30	19/0·143	6,345	19/0·185	3,210
0·40	19/0·165	8,450	19/0·214	4,310
0·50	19/0·184	10,480	37/0·171	5,350
0·60	37/0·145	12,700	37/0·187	6,400
0·75	37/0·162	15,800	37/0·209	7,990
1·00	37/0·187	21,100	37/0·242	10,700

Note.—The areas tabulated are not the nominal areas recommended by the British Engineering Standards Committee. The effective area is that of a solid copper rod having the same resistance as that of the given strand.

Appendix X.

CATENARY WIRES.

The following Table gives the size of galvanized steel catenary strand necessary to carry another cable, assuming the following dips at 22° F. and allowing a factor of safety of 5 and a wind pressure of 25 lb. per sq. ft.

Span in feet	105	120	135	150	165	180	195	210	225	240	270	300
Dips in inches at 22° F. .	18	23·52	29·76	36·74	44·40	62·0	62·08	72	82·66	94·04	119·02	146·94
Equivalent Dips at 60° F. in inches	21·5	27·12	33·35	40·43	48·1	56·02	65·75	75·7	86·5	97·0	122·7	150·7

Let A = weight per foot of carried cable, S = diameter in inches of carried cable, then $A_2 + 1{\cdot}5625\,S^2$ = the figure given in the Table.

Example: To find the size of the catenary cable necessary to carry a cable of 0·725 in. diameter and weighing 0·5 lb. per foot; span 210 ft., with a dip of 72 in. at 22° F., or 75¾ in. at 60° F.

We have $A^2 + 1{\cdot}5625\,S^2 = 0{\cdot}5^2 + (1{\cdot}5625 \times 0{\cdot}725 \times 0{\cdot}725) = 1{\cdot}072$. From the Table below it will be seen that either a 7/10 S.W.G. 40-ton quality, or a 7/12 S.W.G. 60-ton quality, would be suitable.

Number of wires in strand and size of each wire. S.W.G.	7/8	7/9	7/10	7/11	7/12	7/13	7/14	7/15	7/16	7/17	7/18
Values of $A^2 + 1{\cdot}5625\,S^2$, 40-ton quality	2·8187	1·907	1·0841	0·6587	0·3814	0·1952	0·091	0·04763	0·02052	0·006724	0·001358
60-ton quality	8·488	5·813	3·435	2·17	1·325	0·732	0·3756	0·21962	0·11652	0·05443	0·02186

Appendix XI.

The following Table gives the maximum angle of swing on overhead conductors, assuming a steady wind pressure of either 17 lb. or 25 lb. per sq. ft.

Tan θ = (wind pressure per foot of wire) ÷ (weight per foot of wire). The maximum deflection in feet from the vertical = $\sin\theta \times$ dip in feet. The distance between two conductors in the same horizontal plane should be, in theory, more than twice this maximum deflection, though this is not always practicable or necessary.

Nominal Area in square inches	Copper Conductors				Aluminium Conductors of Equal Conductivity			
	Wind pressure 17 lb. per square foot		Wind Pressure 25 lb. per square foot		Wind Pressure 17 lb. per square foot		Wind Pressure 25 lb. per square foot	
	Sin θ	θ to the Nearest Degree	Sin θ	θ to the Nearest Degree	Sin θ	θ to the Nearest Degree	Sin θ	θ to the Nearest Degree
0·0128	0·91	66	0·955	73	0·987	81	0·994	84
0·0163	0·89	63	0·944	71	0·984	80	0·993	83
0·0201	0·869	60	0·932	69	0·98	79	0·991	82
0·0243	0·847	58	0·92	67	0·976	77	0·989	81
0·0289	0·825	56	0·906	65	0·971	76	0·986	81
0·0353	0·798	53	0·889	63	0·966	75	0·983	80
0·0422	0·771	50	0·872	61	0·959	74	0·98	79
0·0499	0·744	48	0·854	59	0·953	72	0·977	78
0·0598	0·713	46	0·831	56	0·944	71	0·973	77
0·0707	0·683	43	0·809	54	0·935	69	0·968	76
0·0824	0·655	41	0·787	52	0·925	68	0·963	74
0·0951	0·628	39	0·765	50	0·915	66	0·957	73
0·1087	0·602	37	0·743	48	0·905	65	0·953	72
0·1257	0·574	35	0·718	46	0·892	63	0·946	71
0·15	0·583	36	0·726	47	0·875	61	0·936	69
0·20	0·532	32	0·678	43	0·846	58	0·919	67
0·25	0·493	30	0·64	40	0·817	55	0·901	64
0·30	0·448	27	0·593	36	0·791	52	0·885	62
0·40	0·404	24	0·544	33	0·745	48	0·854	59
0·50	0·364	21	0·498	30	0·709	45	0·828	56
0·60	0·341	20	0·471	28	0·675	42	0·802	53
0·75	0·313	18	0·436	26	0·634	39	0·769	50
1·00	0·271	16	0·383	23	0·579	35	0·723	46

Appendix XII.

SPECIFICATION.

Testing.—The following tests comprise all that are necessary to prove the correctness of design and quality of material, and are those to which we generally work.

Design test. (*To prove suitability of design.*)—The insulator is subjected to a *gradually increasing voltage* until it flashes over :—

(1) With the surface of the insulator dry : this is known as the "flash over voltage dry."

(2) Under standard precipitation of 1 in. of rain in 5 minutes at an angle of 45° this is known as the "flash over voltage under spray."

NOTE.—Owing to the ordinary variations in the barometric pressure, temperature, and humidity of the atmosphere, flash over voltages necessarily vary 5 per cent up and down.

The insulator is immersed in oil and subjected to a gradually increasing voltage to ascertain its puncture voltage under oil.

A gradually increasing mechanical load may be applied to the insulator to ascertain its ultimate mechanical strength.

Routine tests. (*To prove the soundness of each insulator.*)—Each insulator is subjected to a *predetermined voltage* known as the "test voltage dry" for 5 minutes, such test being less (usually about 20 per cent) than the "flash over voltage dry."

The standard test pressures are as follows :—

Pressure in Kilovolts.

Working Voltage	3,000	6,000	11,000	20 000
Flash over dry ...	46	68	92	105
,, under spray	27	43	62	74
Puncture	74	90	120	130
Test voltage	35	55	72	84

A predetermined mechanical load, usually based upon a factor of safety of, say, 4 on the maximum working load of the insulator, is applied to each insulator for 10 seconds ; this is known as the "Mechanical Test." These tests are usually only taken on suspension-type insulators.

Ironwork.

Mechanical tests.—In the case of fittings on suspension insulators these are usually tested when cemented up together with the insulator. As the pin-type insulator will always stand a load that the spindle is capable of carrying, it is usual to test the spindle separately by fixing the spindle to its shank and applying a predetermined load to the end which goes into the insulator and at right angles to the spindle.

DISCUSSION ON

"THE EMPLOYMENT OF POWER IN H.M. POST OFFICE." *

Before The Institution, 18th December, 1913.

Major O'Meara.

Major W. A. J. O'MEARA : I take it that one of the most important functions of an engineer is to eliminate unskilled labour in every sphere of activity. The author has shown how he and those who are associated with him are engaged in solving this very great problem. I have not seen the statistics in relation to the subject, but I have always thought that in no industry could there be a larger percentage of unskilled labour than in the field of transportation. I think we may say that the greater part of this paper deals with problems connected with transportation, although certainly of a very special kind. I do not think the author claims that what he has been telling us is altogether new, or that if he had his own way all the things that he has been describing would have come into existence in their present form at the present time. Take, for instance, street pneumatic tubes in connection with the telegraph services. As a matter of fact, since the development of telephones one would hardly have thought there was any necessity at all for street tubes for the telegraph service. In many countries users are encouraged to telephone their messages into the office from which they will be transmitted by the telegraph operators. In some street tubes a message takes, I think, about eight minutes—or nearly eight minutes—to travel a little over two miles, and it is really in this direction that time is lost in handling telegrams. In these days of rapid transit, when we can travel such a distance in a motor omnibus in very nearly the same time, it will be seen that there is not a very large field for street pneumatic tubes as a new proposition in relation to the telegraph service. Of course where they exist and there is no other means of surmounting the difficulties, it is right and proper that they should be used and improvements effected such as those described in the paper. There are very few countries where the development of street pneumatic tubes in connection with telegraph services alone has taken place to the same extent as in England. The pneumatic tube question deals only with one part of the problem relating to the acceleration of the

Major O'Meara

* Paper by Mr. H. C. Gunton (see p. 109, No. 225).

O'Meara telegraph service; but I do not wish to take up too much of the time of this meeting, and will now leave the subject of telegraphs for that of posts. The author has also dealt with another aspect of the elimination of unskilled labour. I do not think it can be said that much progress has been made in any country in the direction referred to in the paper in relation to the introduction of machinery in connection with the sorting of letters. As a matter of fact, the problem in question interested me some eight years ago, and I had a model made which I submitted to the Post Office; but I found it practically impossible to interest the authorities. The models were merely inspected and the matter shelved. A few months later I went over to America and there in a Chicago post office I saw—I will not say a really complete installation—but something which went very far towards being a very complete installation of machinery in connection with the handling of letters in bulk and for facilitating the sorting processes. I came back to this country and I discussed the matter with Mr. Gunton, and now he has told us in his paper what he has been doing. Although I have not seen the machinery described by Mr. Gunton, I have, nevertheless, read his description of it, and I may say that he has, in my opinion, made very great improvements on what I saw in America; and in this matter I think he is leading the world.

Wordingham. Mr. C. H. WORDINGHAM: This paper is valuable because it deals with many matters which are official and are not often published; and it gives members a general idea of advances in work with which they are usually by no means familiar. There are just a few points in the paper upon which I should like to comment, mostly in the way of asking for information. I should like to ask the author whether he has found it possible in connection with this multiplicity of services, many of which are repetitions of one another, to go far in the direction of standardization of apparatus. I know by experience how difficult it is to standardize, and I should like to know whether he has been able to do much in that direction: whether he has found it possible to standardize machines for similar services; or whether, if he considers it is not expedient on account of the danger of stagnation in design and the likelihood of throwing the work into the hands of a few makers, he has found it possible to standardize details which, perhaps, are common to a large number of machines. With regard to the arrangement of the power station whereby the low pressure is thrown up to keep the high pressure going in case of breakdown, it would be interesting to know what safeguards are employed to prevent the supply being given from the low-pressure side on a main from which the high pressure is designedly cut off, because it seems to me there might be in certain circumstances a very great element of personal danger if pressure were put on at the sub-station end when the supply was cut off from the generating-station end. On page 111 the use of steam cooking is mentioned as one of the reasons why it was difficult to show economy in replacing the local steam-generating plant with purchased energy. It would be interesting to know whether it has been found commercially practicable to replace steam cooking by electric cooking. Some particularly interesting information is given with regard to the comparative merits and cost of electric lifts and hydraulic lifts, and it would add, I think, to the completeness of the paper if the author could give us a comparison as regards efficiency, Mr. Wordingham. first cost, running cost, and freedom from breakdown between the various kinds of lifts referred to. Then again, I gather that ventilation is in all cases carried out by exhaust fans and not by forcing air into the buildings. I should like to know what kind of fans the author finds most efficient for that purpose, and also what his experience has been of the effect of ozonizers upon the staff in the office in which these are used. I have recently heard it stated that ozone has no germicidal properties, that it simply substitutes one smell for another, and that in large quantities it is poisonous to both man and beast.

Mr. W. SLINGO: I am very glad that the author has been Mr Slingo. given this opportunity of placing before the Institution some record of the great work which has to be undertaken by the Engineering Department of the Post Office. The field which he has covered, as he says, is incomplete: for example, he omits to mention that we are shipowners, that the Engineering Department has its own small fleet of ships, and that those vessels are employed in the repair and maintenance of the large number of submarine cables which there are around these shores. There is, however, one point which concerned me recently—it is perhaps a little outside the subject of this paper—and that is the object which the Post Office engineers have in introducing new ideas. I want, first of all, to impress upon the members of this Institution, if it be necessary, the fact that we do not, as has been suggested, undertake these investigations, nor attempt to introduce any new idea for the sake of amusement or to fill in spare time—we are not in the position of looking out for something new to keep our minds from rusting. I make that remark especially in reference to the new railway, concerning which there are some who think that we do not need it: there are some who think that if we do need it, perhaps we do not know how to make it; and there are others who, if they believe we know how to make it, think that we shall not know how to use it. But, for all that, the fact remains that we are crowding the streets with our mail-vans, and we are suffering delays owing to the streets being crowded by other users. We want the railway, and we are very certain that the railway will prove remunerative, that is to say, that the railway will result in an actual financial saving. In this connection there is one further point which is perhaps worth mentioning, namely, that we are never in the position of undertaking any of these works without being first able to demonstrate to those who control the financial side the actual and absolute fact that on a financial basis we are working upon right lines, that is to say, that we are going to effect a saving as compared with present methods. If there is anything that is necessary to demonstrate the reality of the pressure which is put upon us when we have to start these new works, it is the fact that at the present moment we have a staff of 22,000 men engaged in maintaining and extending our work, and although we have this large number of men we do not manufacture anything that we can get made for us. That is to say, we first of all make one machine, equip it, run it, and try it, and if it proves useful we draw up a specification and then call in the contractors and ask them to go and do likewise—if they can. But there are many instances where we actually find that a contractor does not, because presumably he cannot, work more economically

than we can work, and then we cannot put the thing out to contract; but I am happy to say that I am now trying a very large extension in this direction with a view possibly to increase the scope of the public and commercial interest in our work. Up to the present moment we, like other users of underground cables, have generally bought the cable, drawn it in, and jointed it ourselves. We are placing very extensive contracts now for the manufacture, laying, and jointing of those cables: it is perhaps problematical whether we shall succeed commercially; but I do hope that this first trial will amply demonstrate the fact that a contractor can lay and joint a cable. The introduction, very largely under Mr. Gunton's direction, of motors, cables, and engines for the working of our underground tubes, has been to a great extent forced upon us. Many of the older staff did not like to see recently the old beam engines removed from the General Post Office. Those engines had done their best for close upon 40 years, and apparently they could have gone on for another 40 years. But they had served their day and generation, and they had to be scrapped, not because they were either worn out or useless, but because they took up too much room, and undoubtedly the advance of electrical engineering has enabled us to remove, as in other fields of engineering, large machinery, and to substitute something much smaller and at the same time more powerful. Although we have so many different applications of electricity now to our mechanical operations, and although we do certainly use small currents for much of our work, I think it must be conceded that as an electrical engineering concern, even when it comes to using things in a very large way, the work of the Post Office is worthy of some consideration. It may surprise some members to hear that in the case of a telephone exchange, which is always associated by the public with minute currents, we use secondary batteries having a capacity of 7,500 ampere-hours. I could add, if need be, many other illustrations of the fact that we are not only users of electrical energy in immense numbers of small units, but we also have some small numbers of large units. I should like the members of the Institution to grasp the fact, and they will no doubt do so from this paper, that the Post Office looks upon electricity as its youngest and sturdiest assistant.

Mr. J. S. HIGHFIELD: I had the pleasure some time ago of being taken by Mr. Gunton over a considerable part of the engineering works of the General Post Office, and I am bound to say that what impressed me most was the point to which reference has already been made, the immense variety and the great range of the work dealt with by the Post Office engineers. One part of the paper which specially interested me was the important question of supplying electricity to the Post Office for general power and lighting purposes. It seems to me that it is far more important to get a perfectly secure supply than one at the lowest cost, since the cost of electricity must be an extremely small proportion of the total operating expenses. I think Mr. Gunton is quite right to have done away with the small local plants, although I do not see why it was necessary to erect a comparatively small station supplying from a distance. The small local plants offered the great advantage of being extremely secure, whereas the high-tension plant now used cannot claim the same security. I think that probably the most efficient and secure supply that could be provided would be to work from the public mains and use a local battery as a stand-by. It is difficult to see how a failure could then take place. The whole of the paper, it seems to me, illustrates the difficulty of dealing not only with a great number of small machines of different types, but a great number of men. The difficulty always is to get the man and the machine to fit, that is to say, it is necessary to design machines which the men can work; and when there is a great number of men it may be very difficult to get a radical alteration, even a radical improvement, adopted by an exceedingly large staff. In my own experience I have found it necessary gradually to improve the design so as not to go ahead of the man: that is to say, it is necessary to train the men just as fast as the design is improved. If a machine that is known to be better, but which the men cannot be taught to use, is installed, then slower operation obtains. I cannot imagine a better illustration of the difficulty of fitting the man to the machine, and the way in which the characteristics of the men must be taken into account, than the author's reference to clerks and sorters and how the difference in their work is the first consideration in designing the heating apparatus.

Mr. C. H. PERKINS: One of the most useful purposes which this paper serves is to make those of us who are not in the Post Office Engineering Department more fully appreciate the extent of the engineering work carried out by that Department. In some portions of this work, such as street pneumatic tubes and the plant for operating the same, the Post Office are really the only people who have had any considerable recent experience, and it is with reference more particularly to this branch that I propose to make a few remarks. Recently the Eastern Telegraph Company found it necessary to remove their main London telegraph office to Electra House, and to enable us to meet the ever-increasing demands for improved service it was considered advisable, in order to accelerate deliveries in the city area, to connect up by pneumatic tubes various sub-offices with the new main station. Although we had operated a small installation satisfactorily for some ten or twelve years, the proposed scheme was so very much larger in its scope that it was considered desirable to ascertain the latest practice in the Post Office in order that we might have a really up-to-date installation. We now lease from the Post Office a total of 9 street tubes, the longest being that to Mincing Lane (a distance of 1,677 yards), the total length of these tubes being approximately 4½ miles. All these tubes are naturally laid in some of the busiest and most congested streets in the City, and of course the responsibility for the laying of these additional tubes fell solely on the Post Office engineers. It is, however, more in connection with the plant for operating these tubes, and for the provision of which we had made ourselves responsible, that I wish to record our appreciation of the courtesy and advice which we received from the Post Office Engineering Department. This installation consists of three tandem pumps—two similar 60-b.h.p. sets and one 15-b.h.p. set. The total free air capacity of the installation is 1,800 cubic feet per minute—a mere trifle when compared with the G.P.O. West outfit, but considerably larger than the similar installation at even such a large provincial centre as Birmingham; and the accommodation and installation of plant of this nature in the basement of

Perkins. city offices not designed for the purpose presented some difficulty. Happily so far the whole installation has operated without a hitch—a tribute alike to the Post Office work on the tubes and to the makers of the compressors.

As regards the new Post Office pattern double-slide pneumatic switches, which I have heard are now installed at St. Martin's le Grand also, there are two small faults to which I should like to draw attention. We experience occasional—I almost said fairly frequent, but that scarcely represents the case—breakage of the fronts of the observation and clearing windows. The treated celluloid and mica hitherto employed do not seem to be quite satisfactory. Perhaps the alternation of thinner sheets of both will prove more successful. The other point is the frequency with which the skirt of the carriers is cut away by these switches owing to the somewhat careless and rough handling that must, I fear, be naturally expected from boy attendants. It would be interesting to know whether similar trouble is experienced at St. Martin's le Grand, and, if not, whether anything has been done beyond altering the by-pass or modifying the steel disc which actually does the damage. To illustrate the extent of this damage I would mention that in our recent routine overhaul a bucket-full of small pieces of felt was taken out of our vacuum container. There is one other matter, a small but very important one. Improvements in plant and air switches take place, but the old form of carrier still remains. Perhaps the author will be able to give us a little further information as to the probability of an improved form being available in the near future. Although we have tried other types we have reverted to the old standard G.P.O. carrier, but are very willing to welcome any improvement on this. It is very interesting to note the extension of the use of mechanical conveyers for more elaborate services than those for which they have hitherto been employed. Outside the Post Office service the use of these appliances must of necessity be very limited and on a small scale, but we find that the installation of cord and band carriers in our London instrument room has been most beneficial in reducing delays and keeping the gangways clear of messenger boys.

Smith. Mr. R. T. SMITH : This paper is rather a departure, and to my mind a somewhat welcome departure, from many papers which have been read before this Institution in that it describes machinery driven electrically rather than what may more properly be termed electrical machinery itself. A further interesting point is that the machinery has been designed and specified by the staff who have to maintain it, instead of by engineers whose interest ceases shortly after the maintenance has begun, so that they very rarely have the opportunity of observing and measuring results during maintenance, and so finding out what parts of the design were wrong. Where those who have to maintain machinery which they have specified or designed have the ability and opportunity of making measurements, as is the case in the Post Office, the results are most interesting ; and I think that one of the best things in this paper is the set of comparative curves of cost of hydraulic and electric lifts working under the same varying conditions. Those results could only have been obtained by maintenance engineers having very considerable experience extending over years with that class of machinery. To all those who have to decide, or have to help to decide, between the use of hydraulic power and electricity, the comparative curves of costs given by Mr. Gunton will be useful. The conveyers in the London Post Office building are ingenious and, as has been pointed out before, very varied in purpose and design. With light loads such as occur in Post Office work the energy used for moving the conveyer itself is probably only very slightly increased by the load, most of the energy being used in moving the conveyer. If the author could give us any information on that point I should be glad. When one comes to much bigger conveyers such as are used for carrying coal and minerals, where the energy taken to move the conveyer itself may not amount to 20 per cent of the total energy, the case is different. Such conveyers when raising material from one level to another take the same amount of energy as is taken by a crane, or hoist, or tip to do the same work. The difference between a conveyer and the lift, or the tip, or the crane, is that while in the latter 100 h.p. may be required for one minute, in the former 10 h.p. is required for 10 minutes. From the electrical engineer's point of view it is quite obvious that the conveyer is a very profitable load to supply, as it runs very nearly at 100 per cent load factor while it is working. Mr. Smith.

The way in which the lighting has been arranged at the Post Office building is a tribute to the usefulness of the measurement of illumination on a horizontal plane, which has been much discussed lately. I should like to ask the author whether the amount of illumination is decided wholly from measurements with the lumeter on a horizontal plane, or whether measurements are also taken on vertical planes. In connection with the electric trucks which have been referred to, the Post Office is in rather a better position than some other users in charging the batteries employed with these vehicles. The trouble with the charging is that various voltages below standard have always to be dealt with, such as 60, 80, and 140 volts, and the great difficulty that I see in the development of the truck, which is otherwise most useful, is the charging of the batteries on any commercial circuit. If there are a great many of them it is easy enough, because one can then afford to have a motor-generator and a man to look after it ; but what is wanted for economy in these vehicles is that the ordinary user should be able to plug his cells on to a commercial circuit. The claim for the Jungner and Edison type of battery is that the ordinary user can charge in this way at constant voltage, and if he overcharges he does not do the battery much harm, while if he over-discharges, so long as it is not a short-circuit, the battery is not materially damaged. I should be glad if the author could give us any information as to the arrangements that he makes for charging the comparatively small number of these batteries which the Post Office possess.

Mr. A. J. STUBBS : The general public, and perhaps even electrical engineers, find it difficult to realize how very widely spread Post Office engineering interests are. Mr. Wordingham has referred to "standardization" ; this reminds me that the Post Office Engineering Department is represented on, I think, 9 or 10 of the Committees and Sub-Committees of the Engineering Standards Committee. We furnish a field of training for the Army Telegraph and Telephone Engineers : we touch the Admiralty at several points ; we are in close touch with practically all Government Departments on engineering Mr. Stubbs.

Stubbs. questions ; and, what is perhaps of more particular interest to some members of this Institution, although power users ourselves we have a statutory duty in protecting the huge national plant entrusted to our care against users of power in other branches of electrical engineering. That represents to us a very serious responsibility—how far the strict letter of the Postmaster-General's statutory rights must be enforced, having regard to securing that we shall not, more than is absolutely necessary, hamper expansion of other very important electrical works all over the country. But, of course, as Post Office servants our prime interest in this connection must necessarily be the protection of the huge plant of which we have control.

ushall. Mr. A. W. Marshall : A previous speaker has referred to the difficulty of the inspection glasses on pneumatic tubes : might I suggest that there is a new glass which has been put on the market, consisting of a sheet of celluloid between two thicknesses of glass. I believe it is now available, and I have a piece which has been deliberately shattered and which still holds together. It is perfectly transparent. The inserted celluloid remains intact. I think possibly this may solve the difficulty that has been mentioned. I understand it is being used in submarines, and that the makers are the Triplex Safety Glass Company.

. Rees. Mr. E. W. Rees : The author has amply demonstrated the wide field covered by the Engineer-in-Chief's Department of the Post Office. The figures quoted on page 112 respecting the power station are very satisfactory. The running load factor (70·2 per cent) and the high overall efficiency (87·4 per cent) are exceedingly good, but compared with them the evaporating factor is not so favourable. There is probably some explanation of this. The curve showing the typical daily load at Blackfriars power station demonstrates how carefully the load had been anticipated with regard to the size of the generating sets installed, which is reflected in the very satisfactory running load factor. I have seen the pneumatic plant, and, although the author does not mention it in his paper, he appears to have adopted after-coolers. It does not seem to me to be a case where these should be employed. Having got the energy into the compressed air, it does not seem good practice deliberately to abstract and waste it. I estimate that the loss from this must be something like 16 per cent of the total work done in the pumps. When the air is further expanded in the street tubes saturation may occur under certain atmospheric conditions, with the result that moisture is deposited in the tubes, the speed of the carrier in the tube is decreased, and the loss due to leakage is increased. I suggest for Mr. Gunton's consideration the possibility of cooling the air below freezing-point by means of brine pipes in the vacuum containers. If at all feasible this would increase the weight capacity of the pumps by about 15 per cent, and would dry the air and so prevent deposition of suspended moisture in the street tubes. Indeed, it would effectively dry out any moisture which might get into the tubes from extraneous sources. From a rough calculation it appears to me that a 60-h.p. refrigerating plant would cope with the air dealt with by all the compressors, and this would represent a loss of about 7 per cent, resulting in a net gain of, say, 8 per cent in the useful output of the plant. The method of pumping adopted by the author is extremely useful where pumps show excessive valve losses due to defective design. As regards the lifts, the curves given in the paper are exceedingly useful, but they seem to require some slight modification ; for instance, 6 per cent on the capital cost is allowed for interest and depreciation. This figure seems much too low : it might apply to a direct-acting hydraulic lift, but not to an electric lift. I consider that even a suspended hydraulic lift should be debited with a smaller amount on account of depreciation than an electric lift. In short, I think the point of intersection of the lines referring to hydraulic and electric lifts of similar size should be moved more to the right in Fig. 6, and the curve in Fig. 7 should be drawn higher up. As regards safety, I think every safety appliance which can be applied to an electric lift can now be applied to an hydraulic lift. I also consider that the hydraulic lift still holds the field as regards reliability. Mr. Rees.

Passing to electric lighting the author advocates general lighting under three sub-heads (page 120). In regard to (1), perhaps he will tell us what is his basis of comparison as regards the absence of shadow and eye-strain. In respect to (2), is not the extra cost of lamps in individual lighting set off by the extra cost of energy in the case of general lighting? As to (3), it is thought that the convenience of moving sorting fittings without producing shadows would be more effectually met by making the lighting fitting an integral part of the sorting fitting. Letter sorters have to decipher at the rate of 60 per minute addresses written in all kinds of handwriting on various coloured paper with various coloured ink, and I do not think the illumination provided is sufficient to meet this condition. If a man has a 30-watt lamp under a 9-in. shade just over him, he can increase the illumination on an indistinctly addressed letter through a wide range, which is not possible in the case of the form of lighting advocated by the author.

Mr. C. A. Baker (*communicated*) : The author will perhaps in his final reply explain the considerations which the Post Office Engineering Department had in view when it was decided to erect a generating station for the supply of electrical energy in the London area. During the discussion of this paper the Chief Engineer of the Post Office made a statement to the effect that his Department "does not manufacture anything that can be bought." The main item of interest to this Institution which could possibly come within the category of Mr. Slingo's statement is electrical energy, and surely this can be bought in London in any quantity that the Post Office might require. The Blackfriars generating station is on the south side of the river ; the cost of the energy with a 73 per cent load factor is stated to be 1½d. per unit. On the north side of the river I can buy electrical energy, on a load-factor basis of about 50 per cent for public lighting at a price, which is no secret, of 1d. per unit ; while in another part of London, with a load factor of about 75 per cent, I am able to buy at an average price of 0·96d. per unit. Within the last few years it has been possible to close down two generating stations which were previously supplying the demands above indicated, with resulting economies of £700 and £1,000 per annum respectively. The misfortune of having so many small generating stations in London was emphasized in Dr. Klingenberg's recent address before this Institution,* but of course it was not then presented as Mr. Baker

* *Journal I.E.E.*, p. 123, No. 225.

a new fact. Perhaps, however, reasons of policy rather than of engineering decided the establishment of the generating works, and any information which the author can supply on this point will be of great interest.

Mr. H. C. Gunton (*in reply*): With regard to Major O'Meara's remarks, I am particularly glad that he has given me an opportunity of acknowledging the encouragement which he gave me soon after I came to the Post Office, and it is very largely due to the suggestions that he made on his return from America that some of the appliances with which we have been experimenting have been followed up.

Mr. Wordingham dealt first with the question of standardization. We are doing everything we possibly can to standardize such parts of our apparatus as lend themselves to standardization. It is of course very difficult, as Mr. Wordingham himself has realized, because the designs of a number of different firms have to be considered, and we do not want to reduce competition; in the case of conveying appliances it is particularly difficult. In the case of lifts there is not so much the difficulty of differences in design, but there are still the different forms of supply to contend with. What we do in order to arrive at standardization, so far as it is possible, is to sectionalize the specification: that is to say, we have one part of the specification dealing with the general arrangement and points which vary in almost every case, and another part made up of standard clauses and leaflets. For instance, we have a standard leaflet for the three-phase motor, another for the continuous-current motor, and so on. By the use of these standard clauses and leaflets a specification can be built up with a minimum of labour.

With regard to the possibility of danger when our battery automatically takes charge and keeps up the extra-high-tension supply, I may say that any danger is guarded against by the fact that telephonic communication is established as soon as anything occurs to upset normal conditions, and that any such upset, whether in the form of trouble with a turbo set or a breakdown on the transmission system, would be evident both at the power station and at the sub-station from the behaviour of the plant and the indications of the instruments. Moreover, no circuit is ever assumed to be "dead" until certain precautions have been taken in accordance with stringent regulations.

We have at intervals gone very carefully into the question of introducing electric cooking, and generally I may say that with the prices at which we can buy electricity at present we have not so far been able to make out a commercial case for it. We should be very glad to be able to do so, because it is undoubtedly a much more cleanly and convenient form of heating.

As to electric and hydraulic lifts, and the question of efficiency, first cost, and reliability of the different supplies; so far as three-phase or two-phase alternating-current supply as compared with continuous-current supply is concerned there is not very much in it. Any very slight difference in the efficiency of the motors and control is quite outweighed, as a rule, by differences in the efficiency of the gearing; in this connection I might say that we purposely use low-efficiency gearing to a large extent in order to increase the safety of the installation, and when we install high-efficiency gears we have always supplemented them by emergency brakes, so that if the lift tends to run away there is a ready means at hand for applying a brake. A single-phase supply is much less desirable both as regards efficiency and reliability.

With regard to the system of ventilation, it is usual to use an extractor fan of the propeller or centrifugal type and to admit the air at a suitable height, warming it by means of the radiators. The propeller type is the more efficient where there is a free inlet and outlet. We have been careful to apply ozone in small quantities only, when it has certainly appeared to be harmless and to have a refreshing effect. In large quantities I agree that it might be harmful.

I do not think I need say anything in regard to Mr. Slingo's remarks, as what he said was an extension and amplification of what I have said in my paper.

In reply to Mr. Highfield, I quite agree with what he said as to the importance of security. He referred to the comparative reliability of the self-contained station; that is to say, the station in the basement of the Post Office as compared with having a supply from a distance. I may say that we have been forced, and are being forced, to give up these small stations. We have to find room for considerably more power now, and as a rule we could not extend the plant in the space available. Moreover, a power house in the basement of a building in which a lot of men are employed is not, from a purely humanitarian point of view, a very desirable installation. It tends to vitiate the air of the whole building, and I know that postmasters in provincial towns are generally very glad that we have been able to make a case, and an economical case, for shutting down these steam generating stations. I was particularly glad to hear what Mr. Highfield said as regards the safety provided by the batteries, although I cannot agree that the supply from our own outside station in conjunction with a battery is less secure than a supply from public mains in conjunction with a battery, the former being the arrangement adopted in London and the latter at certain of the larger provincial towns. Personally I should be very sorry to be without the knowledge that we have a battery in one of our sub-stations at the General Post Office, and we do not sacrifice efficiency seriously by introducing them. He also referred to the difficulty of training the men to use new appliances. It is certainly a very big undertaking to introduce any labour-saving device into an establishment in which a large number of men are employed. It is wonderful how helpful they are in trying to make apparatus work, but of course they naturally have somewhat conservative ideas, and patience is required to get them used to new ideas. One great difficulty is the fact to which Mr. Highfield has referred, that with any new invention involving a change of method the process must be slowed up temporarily. Take the case of the sorting-office conveyers. In introducing these the idea was to get rid of the human labour involved in carrying the letters; that is to say, if we can send a letter from one process mechanically to the next process, we not only avoid delay but there is no need for messengers to go round to different points and collect the letters by hand. At first what is saved by eliminating those intervals is discounted by the slower rate of facing and sorting under the new process. For instance, if a man has been used to take up letters and arrange them in his hand in a certain way and put them on a shelf, he does not at once get into

Mr. Gunton the way of taking them up in both hands and putting them in a slot in the table. But as soon as the men get back to what was the normal rate under the old conditions the effect of the improved method of transportation between the processes begins to be felt.

Mr. Perkins has referred to his experience with a new pneumatic switch. We have not had any great amount of trouble owing to the breakage of the windows, but the Eastern Telegraph Company's installation was one of the first which was put in on a large scale, and the experience which Mr. Perkins has had with this installation has drawn our attention to this particular point of weakness. We have altered the design of the window so as to allow of the use of flat glass instead of curved mica or celluloid, and by this means we hope to overcome the difficulty. This also replies to the suggestion kindly made by Mr. Marshall. I sympathize with Mr. Perkins's endeavours in trying to evolve a new form of carrier; we are continually experimenting with new forms of carrier in order to effect improvements. We are trying leather carriers very largely, but it is somewhat difficult to get sufficient flexibility in the head of the carrier so that it will adapt itself to the tube at all points. If these carriers (which have no skirts) can be adopted they will provide a means of overcoming the difficulty in connection with the operation of the new switch.

Mr. Roger Smith referred to the importance of measurements, and I quite agree with what he said. If we are going to learn the maximum that is to be learned from the plant we are using, we must systematically measure.

The amount of energy required in driving conveyers varies so much with different installations that I should not attempt to evolve any formulæ which would represent the power required: it depends on the material used for the band, and the material used for the band necessarily depends upon the character of the load to be carried. The power is also affected by deviations in the route, and I should say at once that the power required to drive various kinds and arrangements of conveyers can only be arrived at through actual experience. With the comparatively light loads with which we have to deal, the additional power to drive the conveyer loaded, compared with that to drive it light, does not usually exceed 15 per cent. The continuous availability of the conveyer from the user's point of view, combined with its high load factor from the supply point of view, should undoubtedly make it a popular contrivance as compared with the lift, as indeed is illustrated by the introduction of the escalator.

The decision which has been come to as to the amount of light to be given is the result of measurements in the horizontal plane at the level at which the work is actually carried out.

With regard to the difficulty of charging batteries on vehicles we are better placed in that respect than most commercial concerns would be. We have power in the form of low voltages available at most of our centres, and we also have the necessary staff to attend to any motor-generators which it might be convenient to provide for this purpose. Mr. Roger Smith spoke rather as if we had a fleet of these trucks, but we are only experimenting with the first at present; so far with very satisfactory results.

Mr. Stubbs dealt with general considerations, and I think I need not say anything with regard to his contribution to the discussion. Mr. Gunton

I was particularly interested in Mr. Rees's remarks, because he was at one time associated very closely with some of the work which he has subjected to friendly criticism. With regard to the low evaporation figure, this was due to poor quality of coal at the time, and was quite temporary. With regard to the use of after-coolers in connection with our pneumatic sets, we have to take a very large view of these matters. If we pumped hot air into our instrument rooms there would be trouble in the summer-time. We have not tried refrigerating plant in the vacuum containers, and I do not think the further complication would be justified, especially as insufficient reduction of the delivery temperature would be obtained. Moreover, the cooling should only be applied to the air compressed, which can only be achieved on the delivery side with the method of regulation employed in connection with this system of "pumping through." Further, the after-coolers not only reduce the condensation in the system of tubes but provide a convenient means of collecting any oil delivered with the air. Mr. Rees also suggested that this "pumping through" system might be introduced in other places where there was room for improvement in the efficiency of the sets. It certainly improves the efficiency of working, and it was due to an investigation by Mr. Rees that the system of pumping through was introduced. He pointed out that although there was a slight percentage of loss in connection with the compression, this was more than counterbalanced by the elimination of the additional plant and valves which it is necessary to employ when separate pumps are used for pressure and vacuum working, and the gain in space is considerable. On the other hand, disadvantages, to which I have referred, are at the same time introduced, there is a much higher temperature of the air delivered, and there is also the danger of drawing in gas in the event of there being any leaks in the street tubes. Of course there should not be any leaks in pneumatic tubes in the streets, but some of our tubes have been laid for something like 40 years, and some of the joints are not altogether perfect. Even if gas is drawn in and an explosive mixture is obtained, an explosion does not necessarily result, but the condition is of course dangerous. We have guarded against this by sampling the air drawn into the vacuum system, and testing for gas; we have also safety devices in the form of explosion valves, so that the effect of any explosion would be minimized.

With regard to Mr. Rees's criticism of the allowance of 6 per cent for capital charges in connection with Figs. 6 and 7, I do not consider that the allowance need be any greater for an electric lift, as compared with an hydraulic lift; as regards the actual percentage adopted, it is of course easy for anybody using these curves to make any necessary adjustment to suit their own allowances, and it was for this reason that the actual figure used was stated. As a matter of fact we should now allow 8 per cent in each case owing to the recent adoption of a more conservative basis for the life of the plant. It is not considered that the cost of maintenance of an electric lift is, generally speaking, more, or the reliability less, than that of an hydraulic lift.

With regard to the question of fittings and lights,

generally speaking I think my contention is correct, that with the system of general lighting we are more or less independent of fittings; and that is a particularly valuable point if light is being provided in a new office under conditions of urgency; that is to say, the lighting installation can be proceeded with and got ready without waiting for the supply of the sorting fittings.

My reference to comparative absence of shadow and eye-strain was in comparison with arc lighting and lighting by individual lamps on the fittings in close proximity to the sorters' eyes. The new method was adopted after careful experiments, and has been generally accepted as the most suitable method of lighting large sorting offices, instrument rooms, and public offices.

Mr. Gunton. With regard to the suggested low illumination, if we do not give our sorters enough light we very soon hear about it. We do not want to give them more than is necessary, and the illumination at present is generally giving satisfaction. If we got complaints on a large scale which were considered justified we should of course seek authority to increase the amount of illumination.

In reply to Mr. Baker's communicated remarks, I may say that the decision to generate our own electrical energy for the General Post Office was only arrived at after carefully considering the price which would have to be paid for it from an outside source in the form in which we required it and having due regard to the all-important consideration of reliability.

MANCHESTER LOCAL SECTION, 16TH DECEMBER, 1913.

Mr. Medlyn. Mr. W. J. MEDLYN: The subject of this paper is not one with which Post Office engineers usually deal, our business being more generally concerned with telegraphs and telephones, and the lighter side of electrical engineering. The author refers to the difficulty caused by condensation of moisture in pneumatic tubes under the streets. We have had a considerable amount of difficulty in this connection with one particular tube at Liverpool, which is in almost continuous use throughout the day; the air is forced in at a temperature of 60° to 70° F., and unfortunately when it cools moisture is formed in the tubes, causing the messages and carriers to become damp. It is therefore important that the air forced through the tubes should be at a low temperature. On page 112 mention is made of the difficulties caused by gas leaking into the tubes. We had a case of this kind in Liverpool where there was a leaky gas main, and also a leaky cast-iron pipe over the lead pneumatic tube, and about 200 yards away there was a leak in the tube itself; the gas was drawn into the tube by means of the vacuum and turned into the containers at the post office. Fortunately the defect was discovered in good time, or the containers might have been transformed into miniature gasometers liable to cause an explosion. The author has not said very much on the question of power supply for telephone exchange equipments. This is a matter which is of considerable interest to Post Office engineers. In the South Lancashire district we have, in the aggregate, a fairly large installation of accumulators varying from 40-ampere-hour capacity to 6,000-ampere-hour capacity. Altogether there are about 64 telephone exchanges and over 30 of these are fitted with accumulators. The total consumption of energy for charging purposes amounts to approximately 200,000 units per annum. Many of the exchanges are of the magneto pattern and will ultimately be converted to "common battery" working, so that the energy consumption will be considerably increased. The author refers to the adoption of a reasonable standard of general lighting. Prior to the introduction of the present system we had a considerable number of complaints from the staff generally, but I am pleased to say that since the system of general lighting was introduced many of our worries in this repect have disappeared.

Mr. Vaughan. Mr. G. H. VAUGHAN: Mr. Medlyn has referred to the inconvenience caused by moisture in pneumatic tubes, apparently due to condensation. Perhaps it will be of interest to mention that a pneumatic tube ticket-distributing plant was installed in the London Trunk Exchange, of which I had charge, and it was essential in order to ensure satisfactory working that the tickets, which were folded in a certain manner, should be perfectly rigid, and also that the tube, which was of rectangular shape, should be free from moisture. The rigidity of the tickets was effected by placing them in an electrical oven and thus extracting all the moisture. In order to eliminate the trouble due to moisture or condensation in the tubes, I suggested that a series of cylinders with closely fitting bags containing calcium chloride should be placed in series between the dash-pot valve and the air container in order to ensure that only thoroughly dried air should enter the tubes. The adoption of this device is, I believe, under consideration. Owing to the well-known hygrometric condition of the Manchester atmosphere it would not be possible to adopt the pneumatic tube ticket distribution system in Manchester unless some such means were adopted.

Professor Marchant. Professor E. W. MARCHANT: There are two points I should like to raise in reference to this paper. The first is with regard to the author's statements as to the improvements in efficiency which he has been able to obtain in the starting of the motors. If a motor, in which the flux per pole is constant, is running on constant-pressure mains, no matter how the current is varied during the process of acceleration the total energy taken from the mains for accelerating the motor is constant. The torque exerted by a motor is proportional to the "accelerating" current. If I be the total current taken, at a pressure V volts, I_f the friction current, and I_A the accelerating current, then $I = I_A + I_f$. The accelerating torque $F_A = k I_A$, where k is a constant depending on the motor. The rate of increase of speed depends on the torque and on the moment of inertia of the moving system.

We may write $k' \frac{dn}{dt} = F_A$, where k' is a constant depending on the moment of inertia.

Hence $k' \frac{dn}{dt} = k I_A$. Integrating this equation from speed o to speed N, we get $k' \int_0^N dn = k \int_0^T I_A \, dt$.

Now $\int_0^T I_A \, dt$ is the total quantity of electricity taken from

Professor Marchant.

the mains to accelerate the motor from speed o to speed N. It follows from this, that if the current supplied is taken from constant-pressure mains, the total energy used in accelerating will be proportional to N, the final speed attained. It makes no difference in the total energy consumed whether the rate of acceleration is small or large, uniform or variable. In this calculation the friction current has been left out of account, but if, as is the case with a lift, this current is comparatively large during the period of starting, it is better to state the result as follows. $I_A = I - I_f$, as above. Hence—

$$k' \int_0^N d\,n = k \int_0^T I\,d\,t - k \int_0^T I_f dt.$$

$\int_0^T I\,d\,t$ is the total quantity of electricity used $= Q$, say.

I_f in most cases is nearly constant. Hence—

$$k'\,N = k\,Q - k\,I_f T,$$

where T is the time taken in starting. Hence—

$$k\,Q = k'\,N + k\,I_f T.$$

From this it is clear that the totai quantity of electricity used during the energy of acceleration will be greater, the larger the value of T, *i.e.* the longer the period of acceleration lasts.

The more rapidly the acceleration is carried out the less the waste in power will be. The results which the author has obtained with shunt motors must therefore be due to the shorter time taken in accelerating the system. With regard to the term used on the last page of the paper, namely, "electric truck," I hope the author will change this to "electric battery truck." The term "electric truck" might be applied to any form of electrically-driven vehicle, whereas this term applies to a battery-driven vehicle.

Mr. Gunton.

Mr. H. C. GUNTON (*in reply*): Mr. Medlyn has referred to moisture in tubes, and I might say that it is for this reason that pneumatic tubes for street work are carried out in lead and for housework in brass. With regard to the danger of explosion from gas, I hope I have not been unduly pessimistic in what I have said. Even if gas of a critical mixture is drawn in, it is still necessary to ignite it before there is an explosion, but it is of course advisable to keep the tubes as free as possible from gas. With regard to telephone exchange equipments, I did not deal with these very fully because they come more under the category of telephone and telegraph engineering than under power engineering.

Referring to Mr. Vaughan's remarks on the drying of air; we are at present experimenting with a view to preventing condensation.

Professor Marchant has dealt with the mathematical aspect of the lift motor. Lift-motor control, however, is very like electric tramway or electric railway control. The pressure is applied to the armature through a series of steps of resistances, and it is these resistances which may unnecessarily waste the power. Some years ago I was engaged on the starting up of an electric railway in London, and we noticed that the consumption of energy from the sub-stations was very much more than corresponded with the consumption of energy that we had previously measured on the trains, even allowing for the losses in the conductor rails and other unavoidable losses, and I found that the drivers were lingering over the operation of the controller. We got them to speed-up the "switching on," and the consumption of energy was considerably reduced; we have effected the saving in lift operation in a similar manner. By speeding-up the controller we are still using the resistances to keep the current within bounds, but we are not lingering too long on one step and then having to accelerate on the next step. What we aim at in the operation of controllers, whether by means of a human driver or by a remote control arrangement, is to maintain the accelerating current at its right value and not to let it decrease.

While I think the term "electric truck" as applied to a truck used between a sorting office and a railway platform suggests a self-contained equipment, I quite agree that "electric battery vehicle" is preferable to "electric vehicle" as a general description of vehicles equipped with batteries.

DISCUSSION ON

"THE BRITISH STANDARD SPECIFICATION FOR CONSUMERS' ELECTRIC SUPPLY METERS." *

YORKSHIRE LOCAL SECTION, 10TH DECEMBER, 1913.

Mr. T. ROLES: I am in agreement with the author's introductory remarks, and his remarks with regard to Clause 2.

Clause 3.—Where strength and shielding from external fields are the main considerations, as in continuous-current work, it is undoubtedly an advantage to have cases made of cast iron or pressed steel, but in the testing of alternating-current meters, especially where adjustments are required, it is often found convenient to have cases of non-magnetic metal, as the meters can then be calibrated without having to replace the cover after making each adjustment. It is also advisable to have meters of comparatively light weight, consistent with reasonable strength and rigidity. This is particularly the case when the instruments have to be carried by hand. Meters with cases which appear to be mechanically strong are invariably subjected to rougher treatment than instruments fitted with light cases. Alternating-current meters having non-magnetic and light metal cases, provided the latter are reasonably able to withstand mechanical injury, are in some instances preferable to meters fitted with cast iron or pressed steel cases.

Clause 6.—The proposed alterations to this clause are urgently necessary; the terminal box and holes should be ample, as suggested. It is often the case that manufacturers do not sufficiently consider the matter from the point of view of those who have to fix the instruments. It would greatly facilitate the connecting up of meters if a uniform system of marking the terminals were adopted. Some makers paste a diagram of connections on the inner side of the terminal-box lid, and in such cases a person of average intelligence experiences little difficulty in making the correct connections. It would, however, be a great convenience if all terminal blocks were clearly marked according to an agreed system. The author does not make it clear whether the holes he mentions are for the copper wire only or for the insulated cable. Terminal lugs should certainly be provided for meters over a certain size, say 50 amperes, it being obvious that a good connection cannot be obtained by the use of two clamping screws where a 500-ampere cable is being brought in, with a hole 1 in. in diameter by 2 in. long. Further, the use of terminal lugs often gets over the difficulty which is experienced in coupling up a small circuit of, say, 3/20 S.W.G. with a cable of very much larger capacity.

Clause 10.—The author's suggestions for modifications of this clause are excellent. My experience is that where the meter cases have to be drilled, however carefully the work is done, particles of iron cling to the magnets and are very difficult to remove without impairing the strength of the brake magnets; in fact, the removal of such particles often necessitates the re-adjustment of the instruments. The manufacturer could drill these holes before the meter was assembled. The size of the owner's labels, as stated in the specification, is on the small side, the labels in use in Bradford being $3\frac{1}{8}$ in. by $1\frac{3}{4}$ in. Mr. Roles.

Clause 11.—I agree with the proposed alterations to this clause. The success of the cyclometer dial depends largely on its being readable without any possibility of error. Difficulty is frequently experienced, however, in ascertaining the correct reading, and we have found many inaccurate records to be due to inefficient cyclometer dials; so much so, that for the present we are refraining from ordering meters with dials of this type.

Clause 12.—In my opinion the term "kilowatt-hour" is preferable to that of "unit." Has the author considered using the term "kelvin"?

Clause 16.—I share the author's opinion that there should be definite figures as to the permissible losses in the main circuits of meters of various sizes.

Clause 17.—I agree that the clause should differentiate between the permissible pressure-circuit losses in continuous-current and alternating-current meters. It is, however, a debatable point whether a reduction in the pressure-coil losses in meters should be obtained at the expense of the meter torque. Four watts per 100 volts is, however, a high figure for alternating-current single-phase meters, and could easily be reduced to two watts for any pressure usually met with in practice.

Clause 19.—I agree with the author in regard to the suggested revision of this clause. A starting current of 0·5 per cent seems to be a fair figure and should be expressly stipulated in the specification.

Clause 20.—The permissible errors in meters from full load to 1/20th of full load should certainly be reduced to at least 2·5 per cent over the whole of this range except for instruments smaller than the 10-ampere size. With due allowance for temperature variation there is no reason why the error should exceed the above limit.

I regret that the author has not taken up the question of the insulating material to be used in meters. In my opinion no ebonite whatever should be employed for insulating purposes. The main insulation should consist solely of mica and steatite, and the use of press-pahn should be restricted to positions where there is little or no pressure. I have received for test purposes instruments in which ebonite and press-pahn have constituted the main insulation. Trouble has, however, been experienced until insulation of a more stable type was employed. Where moulded insulators are used for the terminal blocks, these should be of a standard pattern and composed of material of approved insulating qualities capable of withstanding high temperatures.

Clause 14.—Another point not dealt with in the paper is the question of speed, that laid down in the specification, namely, 150 revs. per minute, being in my opinion excessive. The speed of the rotor should not be greater than can comfortably be counted, and it would greatly facilitate

* Paper by Mr. S. H. Holden (see p. 39, No. 223).

Mr. Roles. the work of testing meters and further eliminate friction in the bottom bearings if it were stipulated that the rotor speed should not exceed 80 revs. per minute and that any speed adopted should be a multiple of 20. The question of constants might also have been touched upon by the author. I am firmly of opinion that the gearing between the rotors and the dials of meters of the same make and size should be uniform. In Chamberlain & Hookham and Ferranti continuous-current meters, after the work of assembling is completed, the speed of the rotor is ascertained and a ratio wheel then inserted so as to obtain the correct reading on the dial. B.T.H. mercury-motor meters are, however, made with a fixed ratio between the speed of the rotor and the dial, and it should be possible for the makers of other types of instruments to adopt the same principle. The use of wheels having different ratios in the same make and size of meter should be abolished, as the use of these frequently leads to confusion when instruments are being tested.

Mr. Fedden. Mr. S. E. FEDDEN: It is quite time that the British Standard Specification should be extended so as to include meters which are used in conjunction with potential and current transformers; such meters are now always used on high-tension and extra-high-tension supplies.

Clause 6.—It is very important that meters should be provided with substantial terminals, and sizes above 50 amperes should be provided with sweating sockets. A common trouble is that sufficient metal is not provided in the terminal block for the screws, and the thread is easily stripped.

Clause 12.—The term "unit" is no doubt better than "kilowatt-hour," as it is always used in connection with the sale of electricity, and is therefore better understood by consumers.

Clause 17.—I consider the limit of 4 watts for each 100 volts of pressure in the potential circuit is far too high; $1\frac{1}{2}$ watts per 100 volts is quite sufficient. It is to be hoped that when the appendix to the specification is published it will deal with the method of calculating the error of a meter so that the percentage of error will be calculated on a uniform principle. The method of carrying out tests on single and polyphase meters should also be standardized.

Mr. James. Mr. S. JAMES: On page 41 the author refers to Clauses 25, 26, and 27, and points out that they are not sufficiently definite. The specification does not mention the limit of error when all the three variations mentioned in these clauses are taken together. It may therefore be inferred that if a meter which is $2\frac{1}{2}$ per cent fast under normal conditions is tested at 0·5 power factor with a 10 per cent increase or decrease in voltage and a 5 per cent increase or decrease in frequency, the meter will still be acceptable if the total error does not exceed $6\frac{1}{2}$ per cent should all the errors be cumulative. Probably this was not intended when the specification was drawn up. The author suggests that the words "shall not cause an error" should be altered to "shall not increase an error." I do not consider that this alteration will have the desired effect. For example, a meter may be $\frac{1}{2}$ per cent fast and a variation of 10 per cent in the pressure may increase the error by 1·1 per cent, making a total of 1·6 per cent. The meter would still be within the $2\frac{1}{2}$ per cent limit permitted, but must be rejected nevertheless. I suggest that the words "shall not cause an error in respect of such variation of more than 1 per cent" be altered to "shall not cause the total error of the meter to exceed $\pm 3\frac{1}{2}$ per cent." I also suggest that the following clause be inserted: "When a meter has a pressure coil and is intended for use on an alternating-current circuit a variation of 10 per cent above or below the marked pressure, and of 5 per cent above or below the normal frequency, at any power factor between unity and 0·5 shall not cause the total error of the meter to exceed $4\frac{1}{2}$ per cent." I mention $4\frac{1}{2}$ per cent because this is the limit allowed by Clause 27. Mr. James.

Clause 26 is not complete without some reference to the power factor at which the test is made. Presumably unity power factor is intended, and practically all good modern meters would comply with this clause under this condition. It does not follow, however, that they will be equally good on a low power factor, as many meters of the induction type are more sensitive to changes of frequency on inductive loads than on non-inductive loads. I do not agree with the author's suggestion with regard to testing dials. If this were adopted, difficulties would arise in large meters running at low speeds. Meters are obtainable which run at 20 revs. per min. at full load, and in a 200-kw. meter the disc would only make 6 revolutions for each revolution of the testing hand. The Canadian Department of Inland Revenue has recently issued an order with reference to the provision of testing dials on meters for sale in Canada, which reads as follows: "Each energy meter must be equipped with a register having at least one dial that will occupy not more than two hours to make a complete revolution when the meter is recording accurately at full load. This dial to be either one of those actually read in computing the amount of energy used by the purchaser, or may be separate therefrom in the shape of a test dial at the maker's option." This is, I consider, sufficient for all practical purposes, as, generally speaking, it is only necessary to take dial readings for the purpose of checking the accuracy of the gearings, and this is usually done on full load. More accurate readings may be obtained by stop-watch tests on all the other loads.

An insulation test with an alternating pressure of 1,500 to 2,000 volts between the windings and the case is in my opinion more reliable, wherever an alternating-current supply is available, than the test specified in Clause 18. Meters which would pass the test when tested with a Megger or similar instrument will frequently break down when operating on a 500-volt alternating-current circuit. Had they been subjected to a 1,500-volt flash test, the weak points would have been at once revealed, and I believe it is the general practice with manufacturers to subject the parts of meters, both before and after assembling, to a test of this description. Continuous-current watt-hour-meters of the commutator type, although not used extensively in this country, should be mentioned, as they suffer from defects peculiar to themselves. For instance, they are easily affected by stray fields, particularly at low loads. If a meter is tested in such a manner that the earth's field assists the main field, a difference of 6 per cent at $\frac{1}{10}$th full load may be observed in some meters when turned through an angle of 180 degrees. This is due to the opposition of the earth's field in the latter case. A similar error may be observed in a meter which is first tested on the positive main and afterwards on the negative. The error may be due partly to

ones. the earth's field and partly to the stray field from the brake magnets, assisting rotation in the one case and opposing rotation in the other. If the brake magnets are shielded by an iron screen, the screen itself may become magnetized, and after a heavy short-circuit on a meter of this description, errors exceeding 30 per cent at $\frac{1}{10}$ full load have been observed. In view of these facts I think it desirable that some clause be inserted fixing a limit to the error caused by reversing the current in the main and shunt coils and to the effect of the earth's field or stray fields of a certain definite strength.

Finally I should like to add a few remarks concerning polyphase meters. All such meters, I believe without exception, give different readings according to the way in which they are connected to the 3-phase supply. If the mains enter in the order, say, 1–2–3, and a set of readings be taken, these will be found to differ from the readings obtained when the mains enter in the order 1–3–2. The difference between the readings will not exceed 1–1½ per cent in good meters, of which there are a few, but in some meters of Continental origin differences of 7 per cent are not at all uncommon. This renders it essential to test on a 3-phase circuit; moreover the meter must be connected on circuit so that the direction of phase rotation is the same as when tested in the test-room. It is desirable that some limit should be fixed to these errors: 1½ per cent would appear to be a reasonable figure. This trouble might be prevented to a great extent if all manufacturers adopted the convention suggested by the National Physical Laboratory some two years ago with regard to the connecting up of polyphase meters and the marking of the terminals. Purchasers would then be able to connect their meters with the same direction of phase rotation as when the meters were tested in the manufacturer's test-room, thus eliminating the error due to reversed phase sequence. Due to the increasing use of a high-tension supply and heavy currents large numbers of series and potential transformers are called for; the various tests with which these accessories should comply ought certainly to be included in the specification in the near future.

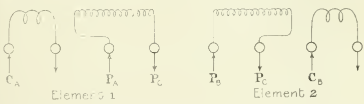
evill. Mr. H. A. Nevill: I quite agree that, at least so far as alternating-current meters are concerned, the Standard Specification requires several alterations.

Clause 6.—In addition to other suggestions that have been made it would in my opinion be of considerable advantage to have the arrangement of the main and shunt connections on alternating-current meters standardized. At the present time each maker appears to have his own particular scheme, and when special meter-fixers cannot always be employed this leads to confusion, and wrong connections are occasionally made. It would also be an advantage to have the position of the terminal box the same in all cases, as at present a change in the make of meter installed frequently means alterations to the connections.

Clause 10.—This clause provides for the fixing of a label belonging to the purchaser, but as far as my experience goes this provision is not generally made except in the case of one make of foreign meters. In my opinion the provision of two holes in the meter case is very bad, as all supply authorities do not, I think, affix labels. Holes in the case of a meter are a temptation to tamper with its working. I suggest that a better provision would be two small rivets ready fixed to attach the label; or even better still, to delete this provision altogether and leave the purchaser to make his own arrangements, as the size of label in use varies so largely. I prefer the Corporation labels to be fixed to the cover of the terminal box. Mr. Ne...

Clause 11.—The author's suggestion for an addition to this clause to provide a jumping cyclometer figure is very good, as it would eliminate the errors in reading which are so frequent where the meter readers are not always the same. This latter remark of course applies more to small systems than to large ones, where a regular staff of meter men are employed. The suggestions relating to the drop in pressure and meter losses are also good; for as far as alternating-current meters are concerned the specification figures are unnecessarily high. Vibration is a great factor in the maintenance of accuracy in the commercial use of meters, and is also a possible cause of creeping. Unfortunately the results of vibration are more commonly found on a consumer's premises than in the test-room.

Mr. R. M. Longman: A standard specification is very desirable, but the present one is very narrow and of very little use, and is hardly used or recognized by anybody. It should be re-arranged and subdivided. First, general rules and observations common to all; then a classification into (1) continuous-current, ampere-hour, and watt-hour meters; (2) alternating-current single-phase and polyphase meters, and (3) current and pressure transformers. Terminals, their size, number, and arrangement, sadly need standardizing, and also the direction of rotation of the armature or disc—which must be clearly visible with the cover on. All meters should rotate in one direction, *i.e.* from left to right when facing the meter, or counter-clockwise when looking down on it, and the terminals should Mr. Longman.



be arranged with the incoming or line terminals on the left-hand side, and the outgoing or load ones on the right-hand side, so that the direction of the current through the meter is the same as the direction of rotation, viz. left to right. A large number of mistakes, leading to reversals and short-circuits, have been caused by the many different arrangements of terminals. For watt-hour meters separate terminals should be provided for both ends of the pressure coil, whether arrangements be made to connect one of them to the current lead or not. For three-phase meters without current or pressure transformers the phases should be kept as separate from each other as possible; for instance, A phase in and out, B phase in and out, C phase in and out, should be the order of the terminals. I have had many cases of flashing-over due to lightning effects, etc., in the meter between terminals of different phases only ¼ in. apart. There is no need for much insulation between the terminals of any one phase, but a maximum amount should be allowed between the different phases. Polyphase meters with current transformers should have

Mr. Longman.

8 terminals, *i.e.* separate current and pressure terminals, arranged as in the diagram on page 213.

There should be no potential difference exceeding 500 volts, alternating or continuous, on any meter; thus on a continuous-current meter for more than 500 volts an external resistance box should be used, and potential transformers, auto-transformers, or external choking coils on any alternating-current circuit having a pressure exceeding 500 volts. The maximum current through any alternating-current meter should be 100 amperes; and even that is a fairly high figure. I do not consider porcelain a satisfactory material for terminal insulation; it is easily cracked, and the cement used to hold the metal part is often a source of weakness. Two screws should always be provided per terminal, and a greater depth of metal must be given so as to give the screws a better chance of holding—in very many cases only a few screw threads are provided, and these are soon stripped.

I certainly agree with the author that cases should be of cast iron or pressed steel, but I think moulded glass should be allowed to stand, as many makers use it for export trade. Many of the thin sheet-metal cases are far too weak, often badly held in position and by no means dust-tight. Further, an iron or steel case is a protection from stray fields—even if it does necessitate the removal and refixing of the cover for every adjustment to the meter. In heavy alternating-current work stray fields must not be neglected. This question of magnetic fields should also be included in the specification, possibly as follows:—A conductor carrying a current of 2,000 amperes, continuous or alternating, and placed in any position at a distance of 1 ft. from the centre of the meter, should not affect its accuracy by more than 0·5 per cent. There should be 5 dials, the value of the first dial division depending on the capacity of each meter. Decimal dials should be painted red. The dial train, cyclometer or clock type, should be in a straight line and as near the glass as possible. I prefer the clock type of dial.

Clauses 16 and 17 certainly require revision on the lines suggested by the author; 4 watts per 100 volts is very excessive. The speed should not exceed 100 revs. per min. for continuous-current meters, and 40 or 50 revs. per min. for alternating-current meters. It would be an advantage if all makers could agree on one standard speed for alternating-current meters, the majority run at either 40 or 50 revs. per min. A speed of 40 revs. per min. is probably the more satisfactory. The pressure test for meters should be 1,000 volts (alternating) for meters up to 250 volts, and 2,000 volts for all meters above that pressure, and the pressure should be applied for one minute. Dr. Garrard's suggestion of 15 minutes is hardly required. For metering polyphase currents, meters should have at least two single-phase elements together on one meter. The so-called balanced-load meters having one element should be prohibited. The use of two or more separate single-phase meters, except in the case of three-phase 4-wire meters when the pressure is taken to the neutral, is not advisable, as at power factors under 0·5 one meter is reversed and it will not register equally correctly in either direction; further, it is likely to be a cause of trouble with consumers. The standard specification for current transformers requires careful handling; the phase angle, of course, should be kept as small as possible, say ½ degree between one-tenth and full load, but in the case of current transformers for high pressures such as 20,000 volts, this may have to be exceeded owing to the requirements of insulation, and of course safety in operation must always come first. Many authorities, however, do not allow metering on the high pressures.

Sufficient attention has not been given to the question of temperature coefficients of continuous-current meters, and this is probably of more importance than the 1/20th load accuracy of small meters. I am glad that this point was gone into by Mr. Fawssett at Birmingham. It should be quite allowable and is most necessary to test current and pressure transformers and meters separately. It is strongly advisable to test polyphase meters on a polyphase load and with the elements in the correct phase rotation. Tests at unity power factor and at a lagging power factor of 0·5 by means of a motor, and then with the direction of rotation of the phases (and of the motor) changed, together with another test at a lagging power factor of 0·5, give a good idea of the correctness of the balance of the elements and of their power-factor adjustment.

Mr. Simpson.

Mr. S. SIMPSON: It is noteworthy that this paper should come from one so closely connected with the meter section of the industry, for this specification should be one of the most important to the supply section in view of its very direct bearing on revenue. With regard to alternating-current meters, it is manifest, the more one considers this question, that revision on lines similar to those suggested by the author is desirable.

Clause 2.—I should like to ask, Why stop at 500 amperes? It is now very frequently necessary to go up to 1,000 amperes and even higher. Perhaps the author has in mind the use of current transformers above 500 amperes. On a medium-pressure circuit at what capacity would he draw the line between putting the current coil in the main circuit and adopting a current transformer with a standard secondary current of 5 amperes at full load? My own opinion is that for above, say, 100 amperes, the current-transformer combination is frequently the cheaper, often more convenient for connecting up, and incidentally simplifies stocking.

Clause 6.—I endorse the remarks by Mr. Roles regarding the desirability for standard marking of terminals and standard connections and as to the use of well-secured terminal lugs of ample size. I have not checked the sizes of the cable holes, but these should as a minimum be such as to accommodate rubber-covered cable based on the Institution rating corresponding to the full-load capacity of the meter. One frequently notices the same drilling for, say, a 5-ampere and a 50-ampere meter; the holes are all right for the former, but quite inadequate for the larger size. A provision for screwed-conduit wiring right up to the terminal cover and in metallic connection with the same is a feature to be commended to the careful consideration of meter manufacturers. Motors, switchgear, and fittings have already come into line in many cases as regards this point, but at present we stop short at the meter in a way which is frequently neither safe nor sightly and is certainly not an engineering finish to an installation.

For a supply authority a provision for stating the purchaser's particulars, such as "(Purchaser's) Meter No. . . . The property of (Purchaser's Name)," is extremely desir-

able, either in the form of a separate label to be fixed subsequently on the front of the case, or as part of the maker's label, but not on terminal covers which, when frequently removed, are apt to be changed from meter to meter in the absence of any distinguishing mark.

The modification of the figures in Clauses 16 and 17 for the number of watts lost is also desirable. Many makers can offer this improvement, and, after all, the determination of this and similar factors in a specification rests largely on what the best achievements are.

Clause 27.—This is very important when dealing with industrial loads of indifferent power factor, and for polyphase circuits. Whether polyphase meters or single-phase meters are used, one element may be running at any power factor down to zero. This power-factor error I think should be graded, and it should be clear that at any rate in the case of single-phase meters the power factor is not necessarily that in the load circuit or the 3-phase power factor, but the cosine of the angle of lag or lead between the current in the series coil and the pressure applied to the shunt coil of the meter.

Regarding the use of polyphase meters for 3-wire circuits, my opinion is that a 2-single-phase-meter method offers the greater advantage, since a ready means of arriving at the average power factor of the load is obtainable from the ratio of the readings, and any serious error is soon detected and located to the faulty element. Moreover, there is very little difference in the first cost, at any rate not sufficient to outweigh these advantages, to which must be added simplified stocking. It will be desirable that, after this specification has been amended, the author's suggestion that meters sold as complying with it should be so marked, be adopted. I would, however, exclude all polyphase meters for balanced loads, which meters frequently lead to much trouble when indiscriminately used.

Mr. Woodhouse. Mr. W. B. WOODHOUSE: The author's proposed addition to Clause 6 would be more valuable if he gave us the basis on which his recommendation as to the size of terminals is made. The size of the terminal holes should depend on the size of the cable required to carry the rated current and on the area of contact between the cable and the terminal block; that is to say, it is governed by the permissible current density in the cable and the permissible current density per square inch of surface contact. The holes must therefore be of a diameter sufficient to admit the proper cable, and on the basis of the Institution rating for rubber-covered cables the diameters of the holes recommended for all meters up to the 100-ampere size are sufficient, but for larger sizes this is not so; for example, a 250-ampere meter requires a 37/0·112 cable, but the hole recommended has a diameter of 0·7 in. and the cable a diameter of 0·728 in. A calculation of the surface available for contact between the cable and the terminal shows that the current density varies from 32 amperes per sq. in. in the 10-ampere size to 95 amperes per sq. in. in the 100-ampere size. The smaller sizes therefore have holes which are too large; but this is probably on account of the design of the clamping screws. I consider that for meters larger than the 100-ampere size the type of terminal discussed is not satisfactory, and that it would be preferable to adopt terminable posts and cable lugs or some other method of making contact.

Mr. Holden. Mr. S. H. HOLDEN (*in reply*): I think Mr. Roles does not fully appreciate the dangers of non-magnetic cases for meters; an aluminium case can be squeezed with one hand so as to touch the armature. The case should always be very strong, for the "ingenious Chinaman" is not by any means confined to China. The faking of meters is carried to the point of a fine art in South America, where devices for making meters read low are actually advertised in the papers. I quite agree as to the importance of a uniform position and marking of the terminals, and I think that for polyphase meters in particular this is important. With regard to the suggested use of the word "kelvin" instead of "kilowatt-hour," the difficulty about adopting that term is that I wish to make the British Standard Specification one of world-wide application. "Kilowatt" is understood everywhere. As to the loss in the pressure circuit, my suggestion was based upon what I believe to be about the best standard practice at present. The specification should contain a provision limiting the character of the insulating materials used in meters. Limiting the maximum speed to 80 or 100 revs. per min. would be an advantage, and the manufacturers would soon fall into line with that suggestion. The abolition of the change-wheel in ampere-hour meters is rather a counsel of perfection, though manufacturers would be very glad to get rid of it. I do not wish to suggest that the manufacturers should always put holes in the meter cases for their customers' labels, but only that there should be a standard size of label and a standard position for it.

Mr. Longman's suggestion as to subdividing the specification for different classes of meters is a very good one. I would carry it even farther and have other sections for continuous-current watt-hour meters and for switchboard meters. My firm have supplied moulded glass covers, but do not find that there is much demand for them. The standard direction of rotation, the standard direction of current, and the standard arrangement of terminals on polyphase meters which have been suggested, are most important. I consider it very necessary that a limiting temperature coefficient should be mentioned in the British Standard Specification. A standard direction of rotation both for the armature and the counter hands is a useful suggestion. My suggested figures for the size of terminals should also be modified as indicated by Mr. Woodhouse.

INSTITUTION ANNOUNCEMENTS.

Annual Dinner.

The Annual Dinner of the Institution will be held at the Hotel Cecil, Strand, London, on Thursday, 5th February, 1914, at 7.0 p.m. for 7.30 p.m. Applications for tickets should be made not later than Saturday, 31st January.

The Wireless Society of London.

Members are invited to a meeting of the Wireless Society of London to be held in the Lecture Theatre of the Institution on Wednesday, 21st January, 1914, at 8 p.m., when Mr. A. A. Campbell Swinton will deliver an address on "Wireless Telegraphy" (experimentally illustrated). During the address special signals, audible to the meeting, will be received from the Eiffel Tower.

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DISCUSSION ON

"BRITISH PRACTICE IN THE CONSTRUCTION OF HIGH-TENSION OVERHEAD TRANSMISSION LINES."*

BEFORE THE INSTITUTION, 8TH JANUARY, 1914.

Mr. W. B. WOODHOUSE: Since Mr. Addenbrooke read his paper in 1905† the question of altering the law in regard to overhead lines has been brought before the Institution on several occasions. I am quite in sympathy with Mr. Welbourn's recommendations, and I wish him success. The comparison of the cost of overhead and underground lines that is given on page 178 is very interesting, but the author does not make it clear whether he capitalizes the cost of wayleaves for the overhead line. That frequently amounts to something like £100 per mile, that is to say, the value of a strip of land 10 yards wide for the whole length of the line. If we had in this country what the majority of other civilized countries have, namely, powers of compulsory expropriation for the purpose of overhead lines, we could, by paying a reasonable price for the land, purchase it outright for a smaller capital outlay than we frequently pay for wayleaves, and we should have what is of vital importance to us—security of tenure. As to design, the formula that the author gives for calculating the pressure-drop is perfectly correct if it is assumed that the current distribution throughout the wires is uniform; but the formula is an awkward one to use. For the purpose of calculation it is much easier and sufficiently accurate for lines such as those which the author considers, to express the drop by $V_R \cos \phi + E \sin \phi$. This is correct to within a small percentage for such comparatively short lines and for lagging currents. The author avoids discussing tension in wires and the effect of elasticity in modifying the stresses due to temperature, snow loading, etc. I do not think a reference to elastic elongation at the moment of fracture is of any value in considering overhead wires, and I would therefore disagree with his suggested specification for aluminium wires. I think it is useless to measure elongation on a 5-in. specimen. The only important elastic elongation that we need consider is that within the working stresses, which the Board of Trade confines to much below the limit of proportionality.

* Paper by Mr. B Welbourn (see p. 177, No. 226).

† *Journal I.E.E.*, vol. 34, p. 511, 1905.

The author seems rather to warn us against condemning offhand the use of aluminium wires. I do not think that is necessary nowadays; but I think we must take into consideration a point which he has not mentioned, namely, that greater sags and a wider spacing of wires are necessary. Therefore the whole supporting structure becomes higher, and heavier because it is wider, and the reactance of the line is increased, that is to say, the pressure regulation of the line is not so good. Taking the author's figures for a 0·15 sq. in. conductor, if aluminium is used the spacing is 29 per cent greater than for copper, and the pressure-drop is increased by about 4 per cent. Mr. Woodhouse

With regard to earth-wires, under the latest model conditions issued by the Board of Trade it is practically essential to consider the use of a continuous overhead earth-wire. I think such a wire is a valuable safeguard. A number of tests taken on earth-plates have shown that the resistance may vary between 5 ohms and 150 ohms. In the dry summer which we had two years ago I know of one case where a 10,000-volt line came down on the sun-baked earth and did not trip the circuit-breaker for an appreciable time. It is thus unwise to depend on a single earth-plate, and to couple a number of earth-plates together with a continuous earth-wire is sound practice. As to the value of the earth-wire as a protection against lightning, I have noticed that with a vertical formation of wires the arcing due to a lightning stroke being followed by the line current has taken place between the top two wires. It rather looks as if the top wires protect the bottom one; but I do not know whether that is really the case. I think I can fully agree with the author's conclusions in regard to lightning arresters. Lightning arresters remind me very much of boiler compositions. Both are an excellent protection so long as the conditions remain the same as those for which they were purchased. Unfortunately, however, the conditions change, and in the majority of cases the arresters are no use; certainly they will not protect any line against a direct lightning stroke.

Mr. Woodhouse

In the case of a direct lightning stroke the trouble is usually quite local, and lightning arresters on another part of the system are of no great value. I do not quite follow the author's argument with regard to the spacing of wires. There is no regular law in the spacing that the author recommends, and I think the minimum spacing with voltages such as we are considering rather depends on the clearances necessary at the points of support. It is necessary to maintain a certain minimum clearance between the conductor and the insulator supports; that in most cases regulates the spacing of the wires, except in the case of very long spans. With long spans the swinging together of the wires must be taken into account; but if we adopt the author's basis, then if the length of the span is doubled the spacing is increased fourfold. Experience, I think, shows that to be unnecessary. The terminal arrangements are really the most important from the point of view of maintaining the supply. The cable dividing-box that the author has shown is very interesting. I should imagine, however, that it is rather difficult to make a good job on the top of a high pole in bad weather. All such boxes have to be filled and the joints made in position; so that it is important to have a box which is easily filled and repaired. I have found from experience that in the type of box having the insulator coming out of the top the insulation breaks down in course of time whatever the design may be. The compound shrinks, the box is heated and cooled every day, and moisture eventually gets in. I quite agree that the conductor should not come out of the top, and I think it advisable that inside the box no part of the conductor should be above the compound. I have tried a design of box which I think gets over the difficulties. The conductor is completely covered by compound; there is no fear of water trouble, and the clearance between the terminals is kept as great as possible. The small amount of clearance provided is a weakness of a large number of boxes, and it is the weakness of the box that Mr. Welbourn has shown us on the screen. The clearance between the conductor and the earthed metal is very small. Not only should the clearance be as large as possible, but it should also be possible to renew the insulators with the box in position with a minimum of trouble.

There is one other point. Fig. 20, which illustrates the method of leading-in bare conductors to the station, seems to me a direct incitement to birds to shut-down that line. I have tried that type of design, and the birds think it is specially designed for their convenience. It would be much better, I think, to bring the slate panel flush with the outer surface of the wall, or to tilt it up so that its forward face is downwards. In conclusion, I should like to say that I think the paper is such an excellent summary of present-day practice and of the points that have to be considered in carrying out this kind of work that it will become the transmission-line engineer's *vade mecum*.

Mr. A. P. Trotter: The ideal of Board of Trade regulations is that they should be a record of the best practice of the day. As practice varies, the regulations should follow. They are perfectly familiar to those engineers who have to deal with overhead construction, and the only complaint made about them by others who are not familiar with such work is that they are too short. Some engineers would like about 25 pages and a roll of blue prints. There are a few purely technical points I should like to touch upon. On page 185 the author observes that the minimum size of wire for high-tension lines is No. 11½ S.W.G. I would say that is also the minimum size that should be adopted for low-pressure wires. It represents a wire of 200 lb. per mile—a gauge always in stock. On page 187 there are two references to insulators which I think are rather contradictory. In the first column on page 187 the author says that the glaze may break and cause the insulators to fail, and at the bottom of the same page he says they must be vitrified throughout. It is of vital importance that the insulation shall not depend upon the glaze. It is important to bind the wire on so tight and so well that it shall not rub the glaze away. A wire working upon the insulator having rubbed off the glaze, the insulator acts as a grindstone and begins to cut the wire through. But quite apart from that it is very desirable that the insulation should be thoroughly vitrified. In that connection I think that the specification for an insulator at the end of the paper is insufficient. I think something should be stated about the nature of the insulation when the glaze has been removed, so as to ensure that it is impossible for moisture to be absorbed. On page 188 the author refers to earth-plates, and I am very glad that at last a statement has been made in print of what an earth-plate should be. Some experiments were made upon the resistance of the earth-plates at my suggestion by one of the firms of contractors who, like so many contractors, are only too reticent in publishing the results of the valuable experiments which they make. I had heard of an earth-plate 5 ft. × 3 ft. which had been specified by an engineer and which seemed to me to be a little bit large. I wondered what the difference between that and an earth-plate a foot square would be, and also between plates of various intermediate sizes. The experiments were made. Plates of various sizes were buried in the ground some 20 ft. apart, and during various kinds of weather current was passed between them, the drop in pressure taken, and tests made. It was found, as the author states, that a plate of about 1½ ft. square is approximately the best size. If a larger size than that is used, very little is gained in most soils; whilst in the case of smaller plates the resistance begins to increase. A plate about 18 in. square and ½ in. thick allows a good bond to be made; and if the plate is specially cast, so much the better. Some engineers go to the "scrap-heap" for plates of about the same superficial area. At the top of the next column on page 188 the author mentions wires coiled up at the base of a pole. That is done by telegraph engineers. It is perfectly obvious that such a coil of wire is of no good whatever for a 10,000-volt line—or as a matter of fact for a 400-volt line. I am glad to see that the author suggests that the earth-wires should be covered in.

Mr. Trotter

On page 192 the author remarks: "Considering these facts, it would seem that the time is approaching when it will be justifiable to ask for the Board of Trade's consent to run high-tension lines along public roads." The time has come; the time has passed some time ago. I have proposed it myself to more than one engineer. That is to say, when I began to be quite familiar with the Merz-Hunter gear I saw that if it could be depended upon to work—and it seems that it will—there was no difficulty in running

10,000 or 20,000-volt wires along the country roads. I have asked engineers whether they would like to do it; but on speaking to those who are engaged in setting out these lines rather than in constructing them, it will be found that they say it is hardly worth doing, simply because any road that is straight enough to be worth while going along is used already by the Post Office; whilst other roads are too winding to be worth troubling about. At the same time where wayleaves—which are a most serious matter—are difficult to obtain, it is quite worth while to threaten the owner that it is intended to go along the road. But there is one thing that I should like to mention about the Merz-Hunter, the Merz-Price, or any other gear. The gear depends, as is well known, upon a small armature that can be attracted. If that works freely and does its work it is all right; but those who have had experience of working with automatic gear know that sometimes if the gear is set fine enough to do the work intended it operates too often. If these gears operate every time that a bird pecks at an insulator or a bit of wet straw blows across the line, and also exhibit nervous tendencies and cause trouble, the obvious thing would be to tie them up with a bit of string.

On page 193 the author speaks of overhead transformers on poles, and he showed a photograph of one of them. I know that transformer, I know of one other, but I do not know of a third. The regulations have been made, but I am bound to say that I do not like this practice. A Japanese engineer called on me some time ago and asked me to show him our protective and safety devices. I wanted to know what he wished to see them for. He replied that there was a law in Japan to have one in every house. I said "Why?" He said the high pressure got on to the low through the transformer. I asked him how that came about as we never had such trouble in this country, and he explained that every transformer in Japan is on a pole outside the house and is a frequent cause of fatal accidents. The transformer illustrated is properly earthed and no doubt is safe, but I should be sorry to see small transformers the size of a hat-box dotted along outside every farmhouse on a 10,000-volt line. Then there is one very small point about the specification for masts to which I should like to refer. The author says that the bottom part is swung up and erected and the joints made. I think the very well-known usage in mechanical engineering should be followed, to have the bolts in shear and not in longitudinal pull. I have seen towers erected and fastened with holding-down bolts, but I do not think that is sound practice.

Commander O. SCHWANN, R.N.: There is one point which I think has not been brought out in the paper, namely, the effect of overhead high-tension wires on aerial navigation. Of course, at the present time aerial navigation can scarcely expect to make very many demands, because it is in its infancy. But I think everybody will agree that aerial navigation is bound to increase, and it seems to me that we might usefully consider a few ways in which overhead wires affect aerial navigation. When the time comes for aeroplanes and airships to be used commercially, they will perhaps be able to demand what they need in this respect. All kinds of overhead wires, both telegraph lines and also high-tension wires, affect the navigation of air craft very greatly. High-tension wires have a particular effect for two reasons; first, the liability of such wires to cause a lighter-than-air craft, *i.e.* an airship or balloon, to catch fire on coming in contact with them; and secondly, the fact that high-tension wires are erected as far as possible in open country clear of roads and towns. As regards setting fire to air craft, this only applies to airships. If an aeroplane strikes an overhead wire it does not very much matter whether it is a high-tension wire or a low-tension wire, because there is sure to be an accident; but high-tension wires are, I think, a distinct danger to airships which happen to trail against them. An airship or a balloon frequently carries a tail rope dragging on or near the ground and suspended from the airship. If that rope earths the high-tension wires, of course it may probably cause trouble to the electrical circuit, but I am not quite sure that it will not also set fire to the airship. The airship has a very large capacity, but I do not know whether the fact of the rope's making contact between the high-tension wires and the airship will not immediately cause a spark which might ignite the hydrogen. The second and more practical case is that all high-tension wires are erected as far as possible in the open country. A navigating air craft expects to be troubled near a town, and it cannot expect to be able to land with safety anywhere in urban districts. But in the open country and across moors where there are no roads, it hopes to be able to effect a landing without striking a wire which at present it finds very difficult to locate. That is the great trouble with high-tension wires, which I believe is chiefly experienced upon moors. The only point that seems to affect the matter at present is the difficulty of finding out where these wires have been erected. I understand it is not very possible to obtain complete charts showing where all such lines are. It is proposed to make aerial charts of England which will indicate the most dangerous lines, so that an airship passing over open country will notice by a red line that it is not such a safe place on which to land as it might be thought from the aspect of the ground. Lines running along roads are of course not so dangerous, as a road is easily seen, and one always expects to find wires there. It seems to me that it cannot be very long before a serious attempt will have to be made to try and let the Aerial Departments have some method of learning where every wire is erected across country, other than along roads or within a certain radius of towns. A great difficulty to which I wish to draw attention is that of seeing the wires. Telegraph wires are very noticeable from the ground, but they are particularly difficult to see from the air. Of course from the aerial point of view one would like to have them made more distinctive, and I suppose that would cause some inconvenience to people living near them. I think that by having them, say, more brightly coloured, or something of that sort, we should be greatly assisted. We are, perhaps, a long way from getting what we suggest, but I merely wish to point out these facts so that they may be taken into consideration.

Mr. C. W. KAY: I should like to describe a new design of steel pole which Callender's Cable & Construction Company have been developing during the past two years. (Mr. Kay proceeded to show a series of slides descriptive of this pole.) It will be seen that the structure consists of five tubes, one vertical tube resting on four inclined tubes, and all five tubes meeting at a point, the complete pole being braced together by wire stays. The

Mr. Kay. design is exceedingly simple and offers a great many advantages over ordinary lattice-work poles, especially as regards shipping and transport for foreign orders and as regards erection anywhere. In the case of such a pole which was tested to destruction, the conductor wires were still well off the ground, and the supply would not have been interrupted. The upper member does not entirely fall to the ground until the deflection becomes so great that the wire stay passes the point where all the tubes run together. In the simplest type of pole where the stays run together at the top, the vertical tube is made thicker in order to carry the bending stress due to the load on the wires. In another design the stays are divided into pairs, and the points where each pair of stays is attached to the upper framework are some little distance apart, the effect being that the vertical member itself is braced and consequently has not to be made thicker as in the previous example. Moreover, the provision of a smaller diameter tube above the cross-arm gives a good shoulder to carry the cross-arm and the pull of the stays. A pole of this type was also tested to destruction. The interesting point is that, contrary to expectation, the pole failed by the vertical member bulging in the direction of the load. Most poles fail by bending in the contrary sense. We tried to find an intermediate position to which to attach the stays, and which would give us neither one effect nor the other. We were largely successful in this. The main wire stays were attached to a different point on the cross-arm from the point where the short upper stays were fastened, in order to brace the cross-arm to the upper part of the vertical tube. A pole of this type was also tested to destruction and, weight for weight, it carried considerably greater loads than either of the previous types. All these poles were designed to fail at four times their working loads, and none of them failed at smaller loads than was anticipated. (Mr. Kay proceeded to show some slides illustrating poles actually erected in the Newcastle district for the Newcastle-upon-Tyne Electric Supply Company, these poles varying from 61 to 65 ft. in height and carrying six wires. Further views were also shown of some poles now in course of erection in South Wales, including several views of poles at the end of a 1,420 ft. span. A noticeable point with reference to these long-span poles was that, contrary to general practice, no substantial modification was necessary in the design in order to carry the extra loads. Another view showed a pole erected at Sheffield, the height of the pole being 81 ft. above the ground.) I think it must be evident to everybody that the maintenance and up-keep of a pole of this design is considerably less than that of an ordinary lattice structure. Painting is a comparatively simple matter, and there are no awkward corners or pockets where water can lodge, and only one side of the material is exposed to the weather. Moreover, the foundation of each of the lower legs consists of a large square plate. One plate out of four at each pole is galvanized and forms a very effective earth-plate.

(*Communicated*) : Mr. Welbourn has asked me what precautions we take to avoid corrosion of our poles, and has suggested that steel poles are unsuitable in the neighbourhood of large towns or in manufacturing centres. Dealing first with the question of corrosion, this might take place on the tubes composing the structure either below ground, due to moisture or impurities in the soil, or above ground due to the action of the weather and impurities in the air. The tubes we are now using are made of high-tensile steel having an ultimate strength of nearly 40 tons per square inch. This steel is far less liable to corrosion than ordinary mild steel or wrought iron, and it is in some respects even superior to cast iron. The closeness of the grain as well as the hardness and uniformity of the material are factors which greatly tend to reduce corrosive action. A large amount of what is usually called "corrosive action" is really galvanic action, and this is naturally less pronounced in a homogeneous material, such as high-tensile steel, than it is in the lower grades. Furthermore, only one side of the material is exposed to the weather, so that, when compared with the lattice towers, these poles enjoy a distinct advantage in this respect. Where the lower ends of the tubes enter the ground they are usually wrapped with a canvas lapping which is thoroughly impregnated with a good bitumen preservative; the insides of the tubes are also well coated with a bitumen preservative. Another point to be borne in mind is that in designing a pole we calculate the diameter and thickness of the tube in order to give it the necessary resistance to buckling. A strut of uniform thickness throughout its length may of course taper towards its extremities, and this is another way of saying that corrosion even if it does take place is only of importance at or near the middle of each tube, and that the tubes may waste away at the ends until their section is reduced to 25 per cent or less of the original area. With regard to corrosion of the wire stays, this is not a serious matter if good material is used. The stays are of course galvanized, and we usually supply them with a factor of safety at least double what is asked for by the Board of Trade. Here again if corrosion does take place it will be a long time before the factor of safety on the complete pole is even slightly reduced. I might also state that there is certainly no reason to anticipate a greater corrosive action on these poles than usually occurs in connection with ordinary wood poles, which are of course dependent on ironwork to a very large extent. It is well understood that in the neighbourhood of manufacturing centres more care must be given to painting, and the expenditure on maintenance must necessarily be higher than on similar work erected in pure country air. The fact remains, however, that nearly all structural ironwork, whether bridges, roofs, machinery, or anything else, is as a matter of fact erected in or near towns and manufacturing centres, and that the upkeep of such ironwork is not a serious matter; nor is the life of steelwork unduly short.

Mr. Vernier. Mr. C. Vernier: I think that this paper is very timely, as although several papers on long-distance transmission in other countries have been presented to the Institution, I believe this is the first time that we have had a paper on overhead lines erected to meet British conditions. It must, I think, come as a revelation to many here to-night to learn that there are something like 1,000 miles of high- and extra-high-tension overhead lines in the United Kingdom, most of which have been erected during the past five years. There are, moreover, 115 miles of lines in operation at a pressure of 20,000 volts. The author says: "It may be taken for granted that pole lines have come to stay." I think the table he has given on page 178

illustrates very clearly why this is so. I only wish he had extended it to both higher and lower voltages, for if he had taken 3,000 volts he could not have made out a very strong case for overhead lines, especially if he had compared them with underground cables designed more in accordance with the work that they have to do than with our engineering standards. An ordinary 3,000-volt cable will withstand a pressure of between 40,000 and 50,000 volts without breakdown, a fact which shows that there is room for a saving in first cost, although this is even more apparent at somewhat higher voltages. At the other end of the table, if the author had taken 40,000-volt lines and cables, the capital cost of the overhead line would only have been about one-third of that of the underground cables. It is not often realized that the cost of an overhead line does not depend within these limits of pressure to any great extent upon the voltage. This is quite clearly shown in the table, where the cost of a 6,000-volt line is given at £900 per mile and that of the 20,000-volt line at £950, the difference being entirely due to the difference in the cost of the insulators. Apart from these the cost of the line depends upon mechanical considerations, and it is merely a question of supporting a certain size of conductor to meet certain wind pressures and of complying with similar factors of safety. Moreover, the lower the voltage the heavier is the conductor usually employed, and the heavier the construction required ; in these respects it is therefore rather to the disadvantage of the lower pressures as compared with the higher. A previous speaker mentioned that the cost of the wayleaves was not included in the table. That is quite true, and I think he mentioned a figure of £100 per mile as the capitalized cost of these wayleaves. I am of opinion that this is perhaps on the low side and will of course vary according to the district, but it must not be forgotten that a great advantage of overhead lines is the fact that they enable "short cuts" to be taken across country. If underground cables be taken by similar "short cuts," wayleaves must also be paid for, while if they are taken along roads without wayleave charges this will add possibly 30 to 50 per cent to the route length, so that the cost of wayleaves is not perhaps so important as it might appear without these considerations. The author has quoted several extracts from an address which I gave recently,* and he has mentioned the difficulty of negotiating wayleaves. This becomes a serious difficulty in some cases because the landowners are able to dictate their own terms. Such a one may be shooting in India for six months, and delay must often occur until he comes back before any progress can be made. If the particular piece of land happens to be in the middle of a long line it is very awkward, and cases have occurred where long lengths of route have had to be diverted. I think it would be an excellent thing if the Institution would consider this matter, although I fear that at the present time there is not very much hope of success ; for our ideas of the rights of landowners have been handed down to us from feudal times, and nothing short of a revolution therein will enable progress to be made in the way suggested.

The second point Mr. Welbourn makes, namely, the curtailment of the absolute veto that the local authorities possess, is one where I think we could make out a good case. I think the clause in the Electric Lighting Acts bearing on this matter arose, if I am not mistaken, from the practice which originated in London of running high-tension wires over house property in the early days of electricity supply. I think it was felt that the local authority should have the absolute right to determine whether it would allow overhead wires of any kind within its district, not only over house property, but also over or along roads and streets. Curiously enough, however, this power was only made to apply to statutory undertakers. I do not see very much objection to the clauses in the case of an undertaking working under a provisional order. If the local authority choose to veto overhead wires in its district, the public whom they represent have to pay for it in the end, as Dr. Ferranti recently remarked. But when we come to consider long trunk lines which may pass through a number of local authorities' districts one single authority should not have the power to jeopardize the success of a scheme. Further, it is not always possible for a company's relations with the local authority to be harmonious, and the absence of any right of appeal in these circumstances may lead to victimization.

Mr. Vernier.

With regard to factors of safety I entirely agree with the author. I have no wish to see any reduction of the factors of safety now allowed by the Board of Trade on the work with which I am connected. The snow-laden wires that the author showed on the screen illustrated an experience that the Newcastle-upon-Tyne Electric Supply Company went through last January. I think it caused considerable surprise. I doubt very much whether many people had any idea that such severe weather conditions were possible in this country, even although those referred to were exceptional. The Newcastle lines weathered the storm, but I think the author gave rather a false impression of what happened. Only four out of 42 lines were affected, and only one very badly so. This was a line carrying a most important supply, and the engineer-in-charge repeatedly switched the line in under practically short-circuit conditions in an endeavour to maintain supply, with the result that the conductors were fused in numerous places. The other lines referred to only suffered to the extent of having a number of insulator pins bent and channels twisted because of uneven snow loading on adjacent spans. One important thing noticed was that the heavier conductors, 0·1 and 0·15 sq. in., did not collect snow, and that no trouble whatever was experienced on such lines. As a result we have since been installing on important lines heavier conductors than are really necessary to deal with the loads, so as to obtain the greater margin of safety. On the question of double-circuit lines, I think that if a duplicate supply be necessary, it should not be provided by making use of a second circuit on the same poles, or even along the same route. The above was the only interruption of supply we experienced during the storm, and in this case the duplicate line was on the same poles pending completion of a ring main. Duplicate supplies should for this reason be given as far as possible by different routes, as in all storms there are areas and certain directions of the lines relative to the storm where the effect is more severely felt, and it is often possible by means of a ring main to maintain the supply over one line when the other is affected. It will be of interest to record that not a single pole was damaged or broken in this storm, and

* *Journal I.E.E.*, vol. 52, No. 223, p. 17.

Mr. Vernier.

that only a few poles, chiefly at angles, were even thrown out of plumb. This compares favourably with the experience of the Post Office at that time, who had numerous poles—many over 12 in. diameter—broken off by excessive snow loading on the wires.

The author mentions that "it cannot be too strongly emphasized that the success or otherwise of all lines will be very largely dependent upon the close attention which is paid both to the design and to the erection of every detail." I certainly agree with this statement. The amount of attention which can be given to details on overhead-line work is really astonishing, and unless such be given, little things will go wrong and cause trouble. Setting-out is one of the most important things in the successful erection of an overhead line, and for this reason I am very glad that the author has inserted the plan, Fig. 1, in his paper. Unless a line is properly surveyed and set out in the first instance, it is practically impossible to obtain a satisfactory result from it afterwards. I have never been able to make out a case for steel poles. We have tried a few, but the first cost and the cost of maintenance, that is the periodical painting, make them unable to compete with wood poles so long as these are as at present so readily obtainable over a large part of this country.

Mr. Jacob.

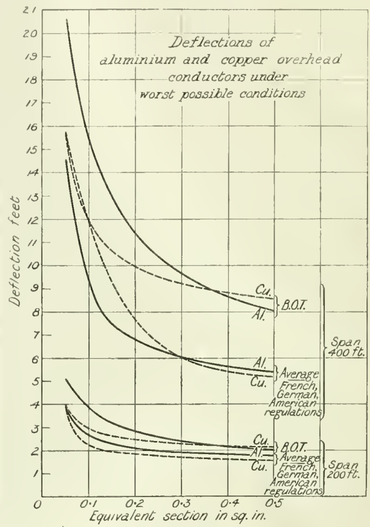
Mr. A. Jacob: If I have a complaint to make with regard to Mr. Welbourn's paper, it is that it stops short at English practice, whereas on the author's own showing the total length of lines in existence in this country at the present time amounts to only 1,000 miles. That length is comparable with one or two of the leading hydro-electric power transmission schemes in operation in Canada and the United States, and I therefore regret that the author did not find it possible to draw some comparison between these long-distance power-transmission schemes and the schemes in existence in England, which are more directly comparable with the intermediate-pressure systems in Canada, the United States, and Scandinavia. It is interesting to note that the author has studied carefully over 500,000 yards of aluminium transmission in operation, and that his experience is of a satisfactory character. To those 500,000 yards I would add from my personal knowledge a further 150,000 yards in this country, and some 15,000 tons of aluminium transmission lines in satisfactory operation in other countries. The author touches the keynote of the whole situation when he points to the restrictions of local and other authorities which militate against the development of transmission lines in this country. I have made a comparison of the regulations in force in Great Britain, France, Germany, and America, and have plotted a series of curves (reproduced in the diagram herewith) which indicate the permissible sag, both in copper and aluminium overhead lines, with pole spacings of 200 and 300 ft. respectively. These indicate that the Board of Trade regulations are still upon a conservative basis.

In the current issue of the *Electrical Review* * there is a description of the nitrate works at Rjukan, Norway. This hydro-electric development is, I believe, one of the largest, if not the largest, in existence. It transmits 170,000 k.v.a. by means of aluminium conductors to the furnace houses, the average pole spacing being 300 ft., and the maximum 820 ft. With regard to snow and ice

* Vol. 74, p. 19, 1914.

Mr. Jacob.

loading, these lines have at times been increased in diameter from 0·88 in. to 10–13¾ in. They, however, only accumulate snow and ice when they are not in operation.



REGULATIONS.

Board of Trade.
Minimum temperature ... = 22° F.
Wind pressure ... = 25 lb. per sq. ft.
Factor of safety ... = 5
Working stress (Aluminium) ... = 5,376 lb. per sq. in.
" " (Copper) ... = 10,752 lb. per sq. in.

French.
Either:
Mean temperature of the district... = 10° C.
Wind pressure per sq. metre of projected area = 72 kg. per sq. metre = 14·8 lb. per sq. ft.
Or:
Minimum temperature of the district ... = − 15° C.
Wind pressure per sq. metre of projected area = 18 kg. per sq. metre = 3·7 lb. per sq. ft.
The set of conditions giving maximum loading is used with factor of safety = 3

German (Verband Deutscher Elektrotechniker).
Temperature ... = 23° F.
Extra load ... = 190 + 50d gm. per metre (d. = diameter in mm.)
Working stress (Aluminium) ... = 9,950 lb. per sq. in.
" " (Copper) ... = 22,750 lb. per sq. in.

American.
Temperature ... = 0° F.
Ice coating ... = ½ in.
Wind pressure on projected area ... = 8 lb. per sq. ft.
Factor of safety ... = 2
Working stress (Aluminium) ... = 14,000 lb. per sq. in.
" " (Copper) ... = 30,000 lb. per sq. in.

This is a curious feature, and seems to be a characteristic of aluminium only, because it does not apply to copper lines. So long as the aluminium lines are alive there is nothing but hoar-frost upon the wires. (Mr. Jacob proceeded to show a series of lantern slides illustrating

overhead transmission systems in Norway in which the maximum pole spacing was 1,970 ft., upon which span an aluminium-copper alloy was successfully employed. Some transmission systems were at present operating at 110,000 volts, and others were now being built for 150,000 volts. Some of these systems showed a greater aggregate length than the total transmission at present in operation in England.)

With regard to jointing, I note that the author advocates butt-welded aluminium connections. This is a satisfactory type of joint where it is not placed under stress, but it obviously has only the tensile strength of annealed aluminium, which is some 50 per cent less than that of the hard-drawn wire. As far as my experience goes, I have always found the torsion-sleeve type of joint to be most satisfactory for use in the run of the line, and it is both mechanically and electrically efficient. I am very glad to note that the author has carried out some practical tests on the elastic limit of aluminium wire, because it is an important point and should be borne in mind when the design of the line is under consideration. I should like to point out that his tests were taken on wire, whereas aluminium is recommended only in the form of a stranded conductor, in which form the elasticity of the material will be much greater. I trust that on some future occasion the author will give us the benefit of his experience of stranded conductors in this respect.

Mr. W. M. Mordey: May I ask Mr. Jacob one question? He says that aluminium wires do not collect ice or snow, whereas copper wires do under the same conditions. This seems a very extraordinary thing. I should like to ask Mr. Jacob whether he can speak on that point from his own experience.

Mr. Jacob: The statement is taken from the current issue of the *Electrical Review*, and was originally made, I believe, by Dr. Marguerre, the expert who constructed this hydro-electric power system. He has had the advantage of carefully watching these lines for some years.

Mr. J. S. Highfield: In regard to insulators, I find from experience that it is most important there should be if possible no moving part between the porcelain and the wire, so that it is impossible for the wire to move with respect to the porcelain. As Mr. Trotter has said, the glaze wears off, and then the wire gets worn through. With the suspension type of insulator considerable care must be exercised to see that the moving parts, which are essential in that type of insulator, are of ample size, so that they will not wear through quickly. With regard to earth-plates, it is much better to use two small earth plates than one large one. There is no reason at all for installing a very large single plate. If several small plates are used they should be between 4 ft. and 8 ft. apart to get the best results.

Mr. J. C. Wigham (*communicated*): The following notes on the overhead work in Cornwall—erected to the designs and under the supervision of Mr. L. A. Hards—may be of interest. There is only about one mile of underground high-tension cable in the county, that entering Penzance. There are 39½ miles of overhead lines, 12½ miles on pin insulators, and 27 miles with suspension insulators. Underground cables would have been impossible, owing to their being too expensive and to the fact that there are no direct roads for several routes. The first lines erected were on wooden "H" poles, 240 ft. span, double circuit (6-wire), copper. The next lines were on steel poles, partly tubular flexible and partly lattice, 400 ft. span, double circuit (6-wire), copper. Latterly some aluminium lines on wood poles, 120 ft. span, have been used. Double-circuit overhead lines are substantially cheaper than 2 single-circuit lines. Aluminium wires on wood poles at short spans are the cheapest construction; but in many cases wayleaves would make such construction impossible. Copper wires on steel poles at 400 ft. spans come out cheaper than on wood poles at 240 ft. spans, and make wayleaves extremely simple; with 400 ft. spans it is possible to place the poles in the hedges uninterruptedly for many miles. To carry aluminium wires on 400 ft. spans means for, say, 0·1 sq. in. copper equivalent, 50 per cent extra windage and approximately 50 per cent extra sag, and the towers must be 6 ft. higher and 50 per cent stronger laterally. As the cost of towers varies approximately as the square of the height, any saving in the cost of conductors is lost in the extra cost of towers.

The pressure of supply is 10,000 volts, but practically all the lines would carry a pressure of 20,000 volts. The only trouble has been with a faulty design of link-type suspension insulator. The Callender clip has been used on pin insulators and has so far proved entirely satisfactory. The storms in Cornwall are the severest in these islands; 90-miles-per-hour gales have been recorded since the lines were erected and have caused no damage. Trouble from birds has been experienced on the pin-insulator lines, notwithstanding the fact that the neutral of the system is earthed through a very high resistance—so high that it is possible to run with one phase earthed. Apparently two birds must have earthed different phases at the same moment.

In regard to wayleaves, the landowners and tenants have, with but few exceptions, been most reasonable. The railway companies and the Post Office have acted as if with the object of facilitating the power company's work, while insisting on their requirements for adequate protection of their telegraph and telephone lines. The Post Office officials especially have gone out of their way to work in with the power company's construction. It is needless to add that the action of the Board of Trade has been throughout to assist and not to retard development. At the same time it is absurd—particularly in Cornwall—that there should be any difference in the legal position of rural and urban local authorities, since there are as important towns in the rural areas as in the urban areas. Because fairly satisfactory wayleaves have been secured, the Cornwall engineers appreciate the highly unsatisfactory conditions under which other power companies have to accept wayleaves, and would heartily support any steps to improve the legal position in relation thereto.

The painting of steelwork is highly important in a salt-laden atmosphere like that of Cornwall. Dixon's graphite has up to the present proved superior to all the kinds of so-called bitumen paints that have been tried. So far the cost of painting has not proved excessive. Telephone circuits are only run on one line; bare copper on rolling insulators. The speaking on this line is not, however, good when there is an "earth" on this portion of the system. The line, which is in sections, is made fast

Mr. Wigham.

at one end, but at the other is attached to a counterweight, which keeps the tension on the line uniform.

Mr. Paton.

Mr. G. K. Paton (*communicated*): This paper comes at an opportune time, and it is to be hoped that the Council of the Institution will support Mr. Welbourn and do something to facilitate the use of overhead lines in this country. In the North Wales Electric Power and Traction Company's system we have scarcely any extra-high-tension insulated cable, the switchboard connections in the power station and all sub-stations being bare, supported on porcelain insulators. Transmission throughout is by overhead conductors, and I may safely say that by no other system is expansion possible. Where consumers are few and spread over a large area the cost of connecting lines must be cut down to a minimum, compatible with sound design and workmanship. Granted that the Merz-Price and Merz-Hunter systems are sound, yet the cost is prohibitive except in large systems where the selling area is compact and the demand large. In circumstances similar to those above referred to, the price per mile of overhead line given by the author might be considerably reduced upon a specification confined to actual essentials, and the comparison with cables would be more in favour of overhead lines. In negotiating power contracts, time is invariably of the essence of the contract, and it is not always possible in these circumstances to elaborate a route plan similar to Fig. 1, especially where the overhead line is of any length. Owners and tenants have to be dealt with, and they may be numerous. When another language enters into the question, as in North Wales, it is an added difficulty to surmount. There is nothing for it but patience and the tactful pursuit and removal of all the real and imaginary objections put forward. Even then one meets with "impossible" folk, and must be prepared to have the route blocked, compelling changes more than once, with consequent delay and loss to all parties—to the owners and tenants due to the driving way of a beneficent enterprise with its uses and amenities, and to the power company and its customers, actual and potential. Thus it is that wayleaves are often the stumbling-block to many useful schemes. Electric power supply companies are *par excellence* public utility companies operating under Acts of Parliament designed as much to serve and safeguard the public interest as to enable the company to earn a reasonable dividend on the necessary investment of capital. Where the public benefit is to be served it should not be left in the unchecked power of individuals to cripple the enterprise by unreasonable demands for wayleave rents or other conditions. The appeal urged by Mr. Welbourn against an unreasonable refusal of consent by a local authority should be widened to include an appeal to the appropriate Government department against unreasonable demands or restrictions sought to be imposed by owners and tenants. If the initiation of such an appeal required the support of actual or potential consumers as well as the power company, with the costs of the application charged to the power company, there would be ample protection against any idle invoking of Government aid.

Insulators and binders.—I must disagree with the author on the question of the flexible binder shown in Fig. 8. The "pigeon" or chafer will not prevent abrasion of the insulator, although it may protect the line wire. I have seen many cases where the soft-copper binder has left its mark on the glaze of the insulator; and the chafer to be effective must be non-metallic. For this reason I adopted leather or pigskin, and either of these meet the case satisfactorily. I would also remark that in the case of the flexible binder 4 or 6 strands of soft binding wire round the neck of the insulator take the strain due to wind pressure where the line wire is on the lee side of the insulator. In the case of long spans where the sag and consequent movement of the line wire on the insulator is considerable, these strands are all bound to stretch in time, and unless the binder is tightened up occasionally chafing will take place. The swinging of the line wire is also an additional reason for having a cushion on the insulator, and I believe this cushion should be between the line wire and the insulator—not between the insulator and the pin. On the only line on which we have insulators screwed on the pins with oiled hemp twine, I have frequently seen insulators rocking on the pin with the movement of the line wire. In any case it is sound practice to cement the insulators at corner poles and terminals, if not on the ordinary line poles, where it may be an advantage to replace an insulator without removing the pin. The binder shown in Fig. 9 suffers, in my opinion, from similar defects to that shown in Fig. 8, and I should think the strands of soft wire round the insulator must sooner or later stretch owing to the swing and vibration of the line wire. For heavy aluminium or copper lines I should prefer to see the line taken over the top groove resting on a leather chafer and then anchored to the insulator on each side by means of a clamp. This would permit ample freedom for the line to swing. The ideal binder should, of course, tie the line wire to the top groove, and the standard design of insulators with comparatively flat upper petticoat is not at all suitable for a side binder, as shown in the illustrations, now that long spans are being used. The author has not given us any information in regard to cement for insulator pins. It would be advantageous to have the experience of other engineers. Preferably the cementing should be done by the insulator manufacturers, as the facilities for doing it in works are much better than on site. As to the earth wire, this should be run overhead if possible, and is much more likely to be of service there than under the line conductors. We have a recorded experience where the overhead earth conductor was actually discharging to the earth-plate two spans distant, the brush discharge effect being actually seen by a visitor. Our experience of the Moscicki condensers is satisfactory so far, and we have not found the cost more than the quoted price for electrolytic condensers. In a mountainous district like North Wales, where our lines are nearly 2,000 ft. above sea-level at some points, it is essential to have protection of some sort. We had a brilliant display of lightning this Christmas, accompanied by heavy hailstorms. Probably we may get more lightning in this district than in other parts of the country. During 1913, vivid lightning occurred on 20 days as recorded by Mr. A. Lockwood, Station Superintendent at the Cym Dyli power station of the North Wales Power Company.

With reference to running telephone lines on the same poles as the power wires, I agree with the author that copper is preferable to phosphor bronze, our experience of the latter not being very satisfactory. In fact, we have had one case where owing to breakage the wire curled up

round the power wires. Undoubtedly a cable system is more secure, but the telephone system is intended primarily for communication to the station, in the event of breakdowns, from any point in the system, and with bare wires this is easily done in conjunction with portable telephones. By these means I have known occasions when the linesman located a fault and replaced a defective insulator in 10 minutes. In practice, rotating the telephone wires and transposing the line wires twice in each section or arrangement of power wires gives the best results. It is extremely unlikely that power conductors should fall, and the result would be serious in either case. Telephone fuses may be replaced quickly and are quite satisfactory in use. It is not good practice to run the telephone wires on spans over 40 yards horizontally as shown in Fig. 14. The wires should be run in vertical formation and "made off" at each transposition to give satisfactory results; but I am of opinion that the power wires should be transposed also.

Guarding of conductors.—The examples of road guards given by the author are all designed to earth the line wire in the event of the latter falling. The only reasonable place for the line wire to fail would be at the insulator, where it might fuse should the insulator break. A second insulator with anchor wire and clamp as designed by Señor Semenza should be quite sufficient to prevent the line wire from falling. Road crossings on this principle have been used in North Wales with the approval of the Board of Trade, although flat cradles have been erected under the wires as an extra precaution.

Mr. J. Nelson (*communicated*): There are several points in this paper which it seems to me require explanation and enlarging upon. In the first place, I do not think the majority of engineers fully realize the great saving in erection costs which can be made by spending a little extra time and care in fully setting out and organizing an overhead scheme before the actual work of erection is begun. It is ruinous financially if gaps have to be left in the line through wayleaves not being settled. The plan shown on page 178 is excellent, but I am sorry to say organization of this kind is the exception and not the rule. I am sure that all who have to do with the erection of lines will agree with me that a far better job can be made of a line when all details are settled beforehand, so that the work can be commenced at one or more points and carried out unceasingly to completion. It is surprising how much money can be saved by keeping up the enthusiasm of engineers and workmen when the work proceeds without hindrance. Factors of safety might also form the subject of a paper. A good many engineers who have not overhead lines on their system seem to look upon the Board of Trade as a bogey; whereas actually that department is always willing to consider special cases. It is quite obvious that any rules framed by a Government department must err on the side of safety for the public, but I think that each overhead line should be judged on its merits. In some districts the Board of Trade regulations are not by any means too high; whereas in others they are much too stringent. I hope eventually to see rules framed which will enable a supply to be given to many villages and farms adjacent to power lines. On page 180 we are given the breaking strain for stays. In connection with stays mention may be made of their various uses: Primarily the object of a stay is to take the extra strain due to the change of direction of a line or the strain due to the termination of the wires. I do not think it is usually realized how important a factor stays are in preventing the line wires swinging together in a high wind. I have watched single-circuit lines erected on single poles under high cross winds, and have noticed the oscillation set up by the difference in the natural swing of the wires and the poles. A certain bad case of the line wires blowing together was cured by fixing stays at the terminal pole and at intervals on the line in such a manner as to keep the pole supports rigid, so that any swing on the line wire due to the wind was not made worse by the difference in swing of the poles themselves.

Galvanizing.—Even when the threads of stay rods or turn-buckles are galvanized and brushed it is just as well to paint them with a tallow and tar mixture so as to make subsequent adjustments easy. In districts where the atmosphere is corrosive all galvanizing should be painted with a preservative compound before the line is put into commission, otherwise the cost of maintenance and renewals will become very high in a few years.

Telephone line.—Fig. 14 shows a very neat arrangement but one which does not seem to be very satisfactory for districts where there is likely to be an accumulation of dirt on the insulators, owing to the small leakage path between the two wires. Possibly the illustration is only intended to be diagrammatic, and if so, it would be advisable in practice to increase the leakage path. A better arrangement is to use double J-bolts and insulators and terminate the wire off each side.

Wood and steel poles.—The author states that there has not been much experience in England of the Rüping process. I understand that on the Continent it has proved very successful—in practice creosote does drain from a Rüpingized pole and renders the ground antiseptic, although the quantity is not so great as with a Bethell pole. With the Bethell process a good deal of creosote is lost before the pole reaches the site of erection; this creosote might just as well be saved at the maker's works.

Guarding.—It is rather difficult to understand why the Post Office allow lines working at pressures below 3,000 volts to cross their wires and forbid lines carrying higher pressures; if the guarding arrangements are adequate, the higher voltage lines could safely be taken across the Post Office wires. High-tension wires have to be kept at least a pole and a half away from the Post Office wires where they run parallel with the latter; whereas low-tension wires are allowed to run parallel with them and as near as 6 ft. Surely the high-tension wires could be carried as near the low-tension wires if suitable guarding were provided. It is reasonable to assume that the inductive effect would be greater on a low-tension line carrying heavy currents than on an extra-high-tension line carrying relatively small currents.

Sundry details.—Where poles are planted on public land, I would propose that the number plates be placed higher than 5 ft. to avoid risk of malicious damage. The trouble due to climbing irons being used is one which can be greatly reduced if the linesmen are made to take short steps in coming down the pole; when long steps are taken it is difficult to get the spur out without tearing the wood. In conclusion, I think the author is to be congratulated

Mr. Nelson. on having compiled so much useful information in the Appendices.

Mr. Donkin. Mr. S. B. DONKIN (*communicated*): The prices per mile for an overhead line at different voltages appear to be higher than those generally obtainable if the cost of wayleaves is omitted. £550 to £600 per mile for a single line of equal capacity to that of the cable would appear to be a more reasonable figure (not including wayleaves). On page 179, under "Mechanical Design Formulæ, Etc.," heading I, paragraph 3, subheading (*b*) and beyond, the word "stress" is used when bending moment would appear to be the correct expression. Again, the formula given under (*b*) expresses the maximum bending moment at the ground line and not at 1 ft. from the ground line: the formula is correct if the words "at 1 ft." are omitted. The same correction should be made in subheading (*c*), and it would be more correct to give the result in both cases in "foot-cwt." instead of cwt. The total effect on the pole is called the "total 1-ft. breaking stress," but the author obviously means that the total bending moment at the ground line is the sum of (*b*) and (*c*). This total should be multiplied by the factor of safety (10), and then gives a value in bending moment which can be found in Table XX of the Post Office Technical Instructions XIII (after dividing the Post Offices values by D, as instructed); and opposite this figure the table gives the diameter of the pole required. Under the headings II, III, and IV, on pages 179 and 180, the word "stress" is used where tension or pull or load is meant. Under heading IV the factor of safety to be used for dividing the total maximum breaking load of all the wires is 5, and not that "to which they are stressed." Heading V would be more useful if altered to "Strength of Insulator Pins"; and a more useful form of equation, using the same notation is—

$$D^3 = \frac{\text{max. pull (lb.) by wire} \times \text{length of pin (in.) from channel to centre of wire} \times \text{factor of safety}}{\text{breaking strength of mild steel in lb. per sq. in. (say 60,000)}}$$

The author says a factor of safety of 4 should be allowed for pins, but he does not say on what loading the strength of the pin is to be calculated. I suggest that the pin should have a factor of safety of 2 when the line wire breaks on one side of it and the unbroken span pulls on it under the worst conditions. This means that the pin would be just strained up to or beyond its elastic limit and would give slightly to relieve itself of the strain. Under heading VIII, on page 180, the column headed "Evenly Distributed Load in Tons" in the table is difficult to understand; but it is presumed that the figures given below this heading are the maximum pull of the stay wire. On page 187, under the heading "Insulators," with reference to the joining together of insulation made in two parts, any form of cement has a tendency to expand and break the insulators, and it seems therefore a safer plan to have the two parts stuck together with the glaze when the insulators are made. In Appendix V, page 198, the note at the bottom of the table would be improved if the words "for the same temperature rise" were added at the end of the note.

Mr. Morton. Mr. J. A. MORTON (*communicated*): First, with regard to the Board of Trade figures for windage and factors of safety. As the author says, the windage is taken at 25 lb. per square foot of plane surface, and the factor of safety at 10 for wood poles and 5 for wires. It is obvious that if these figures are assumed to be safe (which is, I take it, the idea of the Board of Trade) for the worst kind of cross-country work in England, then for overhead distributing mains in say, villages or small towns, the figures are much higher than are necessary, because it is impossible for lines run between houses along streets to be subjected to a wind pressure of this description, or to such hard conditions as a cross-country line. If, however, as the author suggests, the Board of Trade is prepared to relax this rule, the rules ought distinctly to say so and give an idea of what relaxations will be allowed in different circumstances. Then in designing and estimating for lines—which some of us do almost daily—we should know better what basis to work on in any particular case. What the rule does in many cases is to make the construction much more costly than it might be, and so keep back developments or jeopardize the success of small undertakings in villages and small towns where a low capital cost is of prime importance. As an example of this unwieldy construction it is only necessary to look at the lines erected at Brumby and Frodingham, where there are huge poles like Ionic columns (carrying a few comparatively trifling wires) placed along the side-walk, filling the pathway and making the streets even uglier than they were. Further, these Board of Trade figures for poles practically prevent the use of a standard single wood pole which is cheap, can be solidly planted, looks well, takes up little space, and allows simple bracket arms to be used. Standard sizes of single poles can only be used with very light lines where this factor of safety and wind pressure have to be allowed for. One is forced to use very stout single poles, which have to be cut down from much longer poles to get the required diameter and are consequently very costly and ugly, or to use "A" poles, which are also costly and take up a lot of space. But "A" poles are of course impossible for distributing mains in streets or roads, and can only be adopted for cross-country lines. In America even across the plains, where the lines are subjected to very strong winds and worse conditions than we have here, the maximum wind pressure is usually taken at 30 lb. per square foot, with a factor of safety of 6 for wood poles. In considering also the flexibility of wood poles one is further inclined to suggest that the factor of safety should be reduced. If we take a 32-ft. stout single Post-Office-size fir pole planted 6 ft. deep, this would break at the ground line with about 29 cwt. applied at the top across the line. The Board of Trade would only allow 1/10th of this stress, viz. 2·9 cwt., and yet this would probably give a temporary deflection of under 5 in., whereas a reasonable deflection for such a pole would be about $7\frac{1}{2}$ in., and would still leave a factor of safety of $6\frac{1}{2}$. Similar criticism might be applied to the factor of safety which the Board of Trade demands for steel poles.

Now with regard to the question of line-wire dips; these are to be worked out for 25 lb. wind pressure and with a factor of safety of 5 at 22° F., ignoring snow and ice. I have worked out the following table, and in column "D" will be seen the Board of Trade dip required under these worst conditions. As, however, wires can never be erected at this temperature with a 25-lb. wind blowing, it is necessary to find out what dip to give the wires at, say, 60° F. with no wind blowing. This is of course a com-

ton. plicated process, as the elasticity of the wire and the elongation due to the temperature rise have both to be taken into account. In column "E" I have worked out the dip which would have to be given at 60° F. with no wind blowing in order that when the temperature falls to 22° F. and a 25-lb. wind blows the dip would be the Board of Trade figures given in column "D." From these figures we may generalize that if the Board of Trade dip is worked out under the worst conditions, then the wires may be safely erected with that dip at any other temperature on a still day.

TABLE.

A	B	C	D	E
Span in Feet	Size of Line Wire	Material	B.o.T dip at 22° F. with 25 lb. wind pressure. Feet	Dip to be given at 60° F. with no wind to get B.o.T. dip in preceding column when at 22° F. and with 25 lb. wind pressure.
240	1/0 S.W.G.	Copper	4·27	4·47
150	1/10 „	„	2·87	2·60
150	7/0·063 „ (Strand)	Aluminium (Equivalent to 10 S.W.G. Copper)	5·28	4·70

It will be seen from this table that in the case of a 240-ft. span of 1/0 wire the Board of Trade would require a dip of 4·27 ft. Now if the dip were worked out on the assumption that the worst conditions in England would be 17 lb. per square foot wind pressure at 22° F. with an ice accumulation which had doubled the diameter of the wire, then we should find the safe dip under these worst conditions to be only 2·243 ft. with a factor of safety of 2. I consider that such conditions are about the worst that could be reasonably assumed, and a factor of safety of 2 should be sufficient, because an overhead line is a very flexible and not a rigid structure; moreover, angles in a line add to its flexibility and help to relieve the stresses in the line wire when they are getting high at low temperatures. Even the Hydro-Electric Power Commission of Toronto in Canada in working out the sags for important trunk lines take the worst condition as 17 lb. per square foot wind pressure with ⅜ in. of ice on the wires at a temperature of 32° F. and a factor of safety of 2 under these conditions. Their conditions, it must be remembered, are much more variable and onerous than ours. In this case the dip, taking into account the elasticity of the wire, would be 3·65 ft. for these worst conditions. This figure is comparable with the 4·27 ft. Board of Trade dip required under the worst conditions in England. I therefore think that the Board of Trade figures for dip calculations are also too high. It will also be noticed in the case of the 7/0·063 in. aluminium strand that the dip comes out according to Board of Trade figures at 5·28 ft.; this makes it practically impossible to use such a wire. It makes the pole abnormally long and the swing of this wire from the vertical under a 25 lb. wind pressure would be about 5·25 ft.; it would therefore be impossible to put two wires in the same horizontal plane, as we could hardly make the cross-arms long enough, even assuming that such a sight (with the wires hanging in festoons) would be tolerated. Mr Morton.

Next, with regard to the question of resistances in the earth circuits of horn arresters. The natural impedance of any overhead circuit is $\sqrt{L/C}$, and this varies in practical overhead work between 500 and 250 ohms. In any single horn-gap the resistance in the earth circuit should not be less than twice the natural impedance of the circuit; if it is, then the breaking of the current flowing to earth is liable to set up high-frequency oscillations in the wires and the machinery connected to them. If the earth resistance is much greater than twice the natural impedance it might be too high to afford relief to the line. There are, of course, as is stated in the paper, objections to all spark-gaps; but in this connection I would call attention to an article by Mr. A. W. Burke in the *Electric Journal* in June last* on some new ideas in regard to the horn-gap arrester, where the horn arrester is also made to serve as a choking coil and where the line current itself is taken round the horn of the line side of the arrester; that is to say the arrester is in series with the line, whereas at present it is usual to connect the arrester gap in shunt with the line. It is stated that this type of arrester will even operate successfully on a voltage as low as 2,200, and that owing to the magnetic field being increased by the working current flowing round the horn, the additional increase in the electro-dynamic field is sufficient to allow the arrester to operate without any resistance in the earth circuit, the arc rising and lengthening on the horns so rapidly that the earth current is limited almost instantly. Other arrangements of this form of horn arrester are described for voltages up to 45,000; and it is stated that they will operate successfully without causing a disturbance on the line, that they will dissipate an arc before the circuit-breakers can open, that they require no attention, and that they can be mounted out of doors. It is also stated that they have been in successful operation for the past three years.

With regard to the suggestion of getting the Board of Trade's consent to run high-tension lines along public roads where conditions are suitable, I suggest that this is quite the wrong way to get out of the trouble and delay in obtaining private wayleaves, and that the game is not worth the candle. In most cases the idea is impracticable, because most public roads are already disfigured by Post Office telegraph wires, trolley line poles, and sewer ventilating shafts, etc., leaving insufficient room for high-tension overhead lines in addition. Owing to these existing obstructions, very few high-tension lines could be run entirely along the road-side—parts would certainly have to go across private land, and the trouble here would delay the whole line almost as effectively as if it all ran across private land. There would also arise complications due to inductive effects on the Post Office wires along the same road. Further, our roads wind about, which means numerous struts and stays—as in the case of Post Office

* Vol. 10, p. 530, 1913.

Mr. Morton. lines—which add to the cost and in many cases have to be planted in private ground, permission having to be obtained from private owners, with consequent delay. Steel poles strong enough to stand up without staying or strutting might be used at angles, but they are very expensive indeed except for very light lines, and quite impossible on heavy lines. The way out is by legislation making it possible to obtain cross-country wayleaves quickly and on reasonable terms.

Mr. Stubbs. Mr. A. J. STUBBS (*communicated*): As the author has referred to Post Office practice, it may be worth while to mention that, besides providing for a factor of safety of 4 instead of 5 for copper wires, the department's calculations make no allowance for wind pressure. The cases, however, are essentially different. Our structures are generally not so exposed because they are short, and failure involves in our case practically no risk to life. Generally, we are satisfied that we get reasonable immunity at reasonable cost. The author's photographs showing accumulation of snow assist materially to illustrate the conditions. It will have been observed that the accumulation is practically of the same dimension irrespective of the size of the wire. Obviously this will be so, as, having once got a rope of snow, say 1 in. diameter, the succeeding accumulation will not be affected by the dimension of the inner core, upon which the accumulation has formed. Mr. Vernier stated that they have tried to provide for this by increasing the gauge of the conductor beyond what the electrical requirements actually demand. We also do this in regard to very exposed positions, but anything less than 150-lb. wire is not much good for this purpose, and to put that size generally where 40-lb. wire will meet the requirements would clearly be too great a premium to pay for the additional security. It may, however, be of interest to observe that much of the destruction wrought by storms on telegraph lines is due to trees falling across the lines—a condition that no factor of safety can be expected to provide against.

Mechanical design (page 179).—A- and H-poles rarely fail as structures except when, owing to the collapse of wires on one side of a pole, the strain of all the wires on the other side is suddenly thrown upon the pole. In this case of course the strength is only that of two single poles. The author's figures for transverse stress seem to suggest that untrussed H-poles should be very sparingly used. With reference to the spacing of H-poles (page 182), it may be observed that when poles are braced together with parallel centre lines, the clearance between, being wider at the top than at the bottom, causes them to appear splayed out—a rather unsightly effect. We construct with the inner sides parallel.

Effective area of single wires for resistance to wind.—The author adopts 60 per cent of the resistance due to a plane area equal to the diameter multiplied by the length of the wire. The Post Office practice is to take 66⅔ per cent. At the request of the Post Office Engineering Department the National Physical Laboratory has recently looked into this question. The experiments confirm that the pressure is proportional to the square of the velocity of the wind, and the observed effect upon wires 50 mils and 194 mils in diameter show that the Post Office calculations are in fairly close accord with the facts; but the figures work out rather too low. It would appear, therefore, that the 2/3 factor is to be preferred to 3/5. This, however, is scarcely the occasion for going more closely into the details of the experiments. Mr. Stubbs.

Insulator pins (page 180).—For practical purposes our method of testing by load applied on the insulator appears more convenient. The ordinary steel spindle (⅝ in.) breaks at not less than 2,000 lb., and the terminal spindle (¾ in.) at not less than 3,500 lb.

Steel channel (page 180).—No doubt the author has noticed that the length factor has not been defined where he refers to ⅜ in. deflection. I think also he will find that his formulæ want checking—perhaps the factor of safety has not been allowed for.

Creosoted poles (page 183).—The Rüping process has undoubtedly come to stay; but tests which we made some years ago show that the Powell process has little to commend it—the poisoned saccharine matter was found to be washed out after a comparatively short period of exposure. It is a very valuable facility where slotting and boring can be done before creosoting. Poles often rot through moisture getting in at the arm slots, in spite of the treatment of any kind of cut that is made with creosote. We get many good illustrations of the difference that is made by the creosoting process in such connection—for instance, when the core of a pole has rotted there are spurs of sound timber where cracks existed before the creosoting was done, while the sound timber is reduced around the cracks that have formed after creosoting.

Stays (page 184).—I think that the painting of stay threads with the preservative mixture should be made a rule, without exception. Galvanized threads are very unsatisfactory, and we have found it best to have the threads cut after galvanizing.

Telephones (page 190).—The high-tension telephone shown on the screen did not appear quite to tally with the author's description in regard to hearing tubes. If, however, hearing tubes are actually used, our early experience with the Gower telephone may be of interest. We found that the rubber tubes became defective after a time, and seriously depreciated the speaking efficiency. A ready test of the condition of the tubes consisted in making one convolution with a tube, and blowing smartly into the ear-piece. If the tube was sound, it gave a sharp whistle.

I am a little sceptical as to the case made out on page 192 for the abolition of guarding on the score of equipment of lines with automatic protective apparatus, especially in view of the recognized possibility of a shut-down of the line by the operation of crows, as described on page 186. It is believed that in such circumstances the switchboard attendant resets the circuit-breaker and perhaps holds it momentarily in position so as to burn off the trouble. Such resetting of the safety devices seriously discounts their protective value even if, as was suggested by one speaker, their inconvenient sensitiveness has not been already corrected with the aid of string.

Mr. H. BRAZIL (*communicated*): There are one or two points in connection with the protection of the line that I should like to discuss, as I am afraid I am not in agreement with the author upon this matter. The particular sentence on which I wish to base my remarks is the following: "The author is strongly of opinion that any form of arrester which involves a spark-gap is wrong in principle, Mr. Brazil.

zil. because of the high-frequency oscillatory disturbances caused by a spark in a circuit." In a footnote to his paper the author quotes Mr. Duddell's Presidential Address in support of his argument, but I also wish to quote this address in support of my side of the question. I do not wish to suggest for a moment that Mr. Duddell's address is contradictory, but I venture to think that the mistake is Mr. Welbourn's in grouping together all spark-gap arresters, whether they break the circuit by means of a spark or by means of an arc. It is the difference between an arc and a spark that I wish to discuss, and on this point I will quote Mr. Duddell as follows : "The fundamental difference between an arc and a spark is that in the arc the electrodes are being continuously volatilized, and the vapour of the electrodes takes part in the passage of the electric current. The spark, however, is generally of an intermittent or transitory nature, the electrodes are not appreciably volatilized, and the current is largely transferred through the air." Throughout his address Mr. Duddell warns us that we must not break circuit rapidly as when this is done (and this is what I call a spark) serious pressure rises occur. Whereas, on the other hand, I would again quote Mr. Duddell : "I have not yet come across a well-authenticated case in practice of an arc acting as a musical arc and producing dangerous pressure rises." To my mind, breaking circuit by means of a spark in the one case, or by means of an arc in the other, is analogous to breaking circuit with a quick-break switch, as against breaking circuit through a continuously increasing resistance, and I need scarcely point out the advantage of the latter proceeding.

Mr. Welbourn condemns horn arresters entirely, but I should like to quote a few things in their favour. For 10 years past I have had experience with a system having 50 horn arresters installed, and I can testify that far from their being a source of trouble to us they have been very beneficial. Before these were installed we had a very large amount of trouble with surges, and this was very greatly reduced when the horn arresters were installed. Further, in one case where, owing to a mistake, a man left the horn arresters disconnected on a certain part of the system, several machines broke down, but after the horn arresters were reconnected these troubles disappeared. These horn arresters have indicating arrangements attached, and to my knowledge they have discharged over 1,000 times, relieving the system without causing trouble. I would also call attention to an article by Mr. W. A. Coates in the *Electrical Review** for 26th December, 1913, in which he gives particulars of some very large systems working with air-break switches and horn lightning arresters. The main contacts of the switches are first broken, and the arc is drawn out on a pair of horns, so that the action is similar to a horn arrester. Oscillagraph records of a switch opening a load of 1,000 kw. at a pressure of 33,000 volts show no disturbance of potential; and a subsequent test in which a load of 8,000 kw. was switched off gave similarly good results. This I believe to be entirely due to the gradual breaking of the circuit caused by the continually increasing resistance of the arc as it grows longer. I am convinced that where trouble has been experienced with horn arresters on overhead lines it

* Vol. 73, p. 1043, 1913.

is very often due either to the fact that no resistances are put in circuit with the horns, or that the resistance is not properly designed or of sufficient capacity. It is essential that the resistances shall be able to stand a very heavy load for a short time; and of course they must be absolutely non-inductive. A considerable number of such resistances of the carbon-powder type have been installed on the Cornwall Electric Power Company's system, and are working very satisfactorily. If we accept Mr. Welbourn's condemnation of spark-gap arresters, this eliminates practically every type, including the electrolytic arresters, which have a horn in series with the aluminium cells, and which are so largely used in America. The only type that is left is the Moscicki condenser. While quite admitting that these are valuable for dealing with surges of very high frequency, I would point out that they are useless when a surge has a frequency of, say, 500–1,000 $\sim$ per second, a very usual frequency for surges caused by "earths" and short-circuits. (See Messrs. Creighton and Sprong's paper in the July, 1909 number of the *Proceedings of the American Institute of Electrical Engineers.**) I think it is quite clear that the danger to be avoided in lightning arresters is that of making the rate of change of current very great, that is to say, switching-off rapidly; and I would suggest to Mr. Welbourn that arrester horns with a suitable resistance in circuit will not break the circuit quickly, and therefore should not give trouble due to high-frequency oscillatory discharges.

Mr. C. WADE (*communicated*): I was pleased to see the author's favourable remarks *re* the cost of overhead lines and the use of wood poles. I was also glad to note last spring that the Board of Trade had reduced their wind-pressure requirements, thus allowing the size of poles to be slightly decreased. It always seems to me that the difficulty of obtaining wayleaves is one of the most serious troubles preventing the greater use of overhead lines. As the author says, the law relating to the same should be revised, and I think the granting of wayleaves should be made compulsory. With regard to preserving timber poles, I agree with the author's remarks *re* the preparation of the same, but I rather doubt the efficacy or necessity of the tarring-over of the pole butts, etc., or of the creosote in the ground at the foot of the pole. The Rüping process of creosoting, of which my firm were practically the pioneers in this country, appears to be giving universal satisfaction and superseding the old Bethell process. There is no doubt Rüpingized poles or cattle-guards can be painted a few months after erection, and the Post Office and my firm are experimenting to ascertain the most suitable paint. I should never think the Powell process or any other process will be a serious rival to creosoting in this country. I investigated this process some years ago, and its advantage seemed to me to be in its claim to withstand the attacks of white ants in tropical climates.

The question was raised at the Yorkshire Local Section discussion as to the relative strength of "A" and "H" poles. This point has been raised several times, and I have considered the advisability of making tests. The strength of H-poles, however, would appear to be entirely governed by the amount of bracing and the distance apart of the members; and as it would mean such extensive tests to include poles used by various

* Vol. 28, p. 867, 1909.

Mr. Wade. engineers, I have not done anything up to the present. I will, however, consider the matter. I have generally assumed that a properly made H-pole as generally used is of about the same strength as an A-pole, which is very similar to what Mr. Welbourn said.

Mr. Fox. Mr. E. J. Fox (*communicated*): I am unable to agree with the author's statement as to the merits of steel and wood poles. Mr. Welbourn seems to some extent to condemn steel poles because he has come across instances where steel tramway poles have corroded in a comparatively short time. It is generally accepted that under certain conditions iron and steel require more careful protection than under other circumstances. As an instance I might mention a corrugated iron roof covering an area of about 10 acres and exposed to the atmosphere both outside and inside, the works in question being in this respect similar to a railway-station. The outside of the roof requires painting about every two years in order to protect it from corrosion, whilst the inside has not been touched for 14 years, and is to-day in as good a condition as when new. In one small portion where locomotives run underneath the roof the sulphurous discharge has tended to corrode the inside of the roof immediately above the discharge from the locomotives, whilst the adjoining portion—as already mentioned—shows no signs of deterioration after 14 years' use. On one important point engineers and buyers can ensure their steel poles having the longest possible life, namely, by excluding high-tensile steel, of which poles are sometimes made. Most chemists will agree that high-tensile steels tend to corrode more quickly than either wrought iron or mild steel; and this is probably due to the higher percentage of manganese and carbon present in high-tensile steel. Mild steel with a tensile strength not exceeding 24 to 28 tons per sq. in. will give the best results in the direction of the minimum tendency to corrode. Engineers would do well to specify the steel of which their poles are made to fall within this figure. The following shows the percentage of manganese and carbon present in various average samples of iron and steel of which these poles are made :—

	Iron	Mild Steel.	High-tensile Steel.
Manganese ...	0·030 %	0·320 %	0·750 %
Carbon	A trace	0·100 %	0·320 %

Mr. Trechmann. Mr. H. K. Trechmann (*communicated*): This paper offers very little scope for comment. It would not have been without interest, however, had the author added a section on the probable direction which future developments will take. It will be noted that he justifies the use of overhead lines by their cheapness, and shows that by the extended business resulting from their use benefits are reflected upon practically all branches of the electrical power supply industry. Here then may be seen where further developments are to be expected. To benefit the community as a whole and the electrical industry therewith, the price of electricity must be reduced (*vide* Dr. Ferranti and others); and in effecting this desirable state of affairs the cost of all items concerned in its production and distribution must receive attention. Both Continental and American practice are to be regarded as considerably ahead of English practice in respect to overhead work generally, and in America especially there have been marked developments in connection with apparatus for outdoor use, such as overhead air-break switches, and in fact all apparatus necessary to equip complete outdoor sub-stations. Indications are not wanting in the paper that English practice will, in order to make progress, follow to some extent at least the example of American and Continental engineers. For instance, the terminal pole in Fig. 12, with its special housing for Moscicki condensers, may be regarded as a small step in that direction. The lantern slide showing an overhead transformer is also a case where overhead switching might very appropriately be employed. Mr. Trotter does not regard the placing of transformers on poles as good practice, but if the electrical conditions could be made to correspond with those of transformers in sub-stations there would be no essential difference between the two situations other than that of cost. Overhead switching would appear to be the only medium for obtaining proper control of transformers placed on poles, and though they are not beautiful they certainly are "load," and therefore not to be despised. In practice also cases frequently occur where switching arrangements are desirable, but where the circumstances do not justify the cost of building and equipping sub-stations. As regards the protection of lines from surges, the system adopted by Messrs. Merz and McLellan is stated to be both effective and cheap, although as the amount of added insulation appears to be something between 20 and 30 per cent of the total on the high-pressure side of the transformer, it might have been expected that some considerable increase in both size and price should have taken place. It would be interesting to know if any figures are available as to the effect on the reactance of the transformers when fitted with reinforced insulation in the manner described.

Mr. Driver. Mr. E. T. Driver (*communicated*): There are many technical advantages accruing from the use of aluminium conductors other than that of economy. In the early days of overhead transmission the line voltage was limited by the insulation of the transformers used in conjunction with the line. Such transformers then began to receive more attention, and with the advent of the oil-immersed transformer of improved design and more reliable insulation the limiting factor in line voltage became the line insulators. These in their turn were improved to meet the requirements called for, and finally with the replacement of the pin-type insulators by those of the suspension type, pressures of 150,000 volts have been rendered possible. Several lines of this voltage are now in the course of erection. With the employment of such voltages, however, another difficulty has been encountered, namely, corona loss. This subject has been exhaustively studied by Mr. F. W. Peek, who has shown that the corona loss is a function of the diameter of the conductor. Now for equal conductance the diameters of aluminium and copper stranded conductors are in the ratio of 1·29 to 1, and Mr. Peek's experiments have shown that the critical voltage for the aluminium conductor would be some 20 per cent higher than for the copper conductor, due to the 29 per cent greater diameter of the former. As an example, copper conductors of 0·06 sq. in. section with a 10-ft. spacing would give a corona loss after a pressure of 86,000 volts had been reached, whereas with equivalent aluminium conductors the corona would not occur until a pressure of 106,000 volts had been reached. Assuming

a line pressure of 100,000 volts, there would be a loss with the copper of some 3 kw. per mile of single-circuit line, whilst the aluminium line would give no loss at all from this cause.

Turning now to lower line pressures, such as are used in this country; where such extra-high pressures as above mentioned would not be commercial propositions, owing to the very short length of the lines, aluminium will again be found to possess advantages over its heavier competitor. It has often been stated that the 29 per cent greater diameter is a serious drawback on account of the larger wind pressure. Under the Board of Trade Regulations overhead conductors must be erected to withstand a wind pressure of 25 lb. per sq. ft. with a factor of safety of 5 at the minimum temperature. With a conductor of 0·1 sq. in. the ratio of wind loading to the weight of the conductor itself is 4·3 to 1; but with a conductor of 1·0 sq. in. this ratio becomes 1·3 to 1, and it will be found that the deflections under certain conditions of wind and temperature are often considerably less with aluminium than with copper, especially on conductors of over 0·5 sq. in. equivalent copper section. As tending to offset this 29 per cent increase in lateral wind pressure, it must be remembered that the lighter conductors predicate approximately 20 per cent less longitudinal pull in the line than on the equivalent copper line, thus making it feasible to employ a supporting structure of slightly different design, and costing not much in excess of those on the copper line. It will thus be seen that aluminium can advantageously be employed both on low-tension and extra-high-tension systems; and although there would appear to be a larger field for this latter type, which allows long spans and flexible or elastic tower work, such as we cannot employ in this country. Yet the fact must not be overlooked that many of the largest schemes of this type abroad have been and will be engineered from this country. Another point sometimes put forward is that the self-induction of aluminium conductors is greater than that of copper conductors. This, however, need not be so. In the first place the self-induction is a function of the ratio of the conductor spacing (S) to the diameter of the conductors (D); and consequently for any given value of this ratio (S/D) the self-induction is constant. The larger deflection of the aluminium conductor of course necessitates a larger spacing on the cross-arms, but D is increased as previously stated by 29 per cent. The increase of S is not nearly so much as this in the majority of cases; the net result being that the value of S/D for aluminium may be the same as for copper, and even less under certain circumstances. Next, considering capacity, which is a function of D/S, this may possibly be larger for aluminium than for copper, but in most cases capacity may be neglected when considering the regulation of the line, so that there is no reason why the pressure regulation of an aluminium line should not be as good as that of the equivalent copper line.

With regard to steel supporting structures, those of the tubular type would appear to possess several advantages over those of the lattice type. For equal strength the tubular structure is much lighter and therefore cheaper, and experience up to the present seems to indicate that the tubular pole has a longer life than the other type. One objection is that firmer foundations are required, and in certain soils it may even be essential to employ concrete foundations. This would, however, probably be necessary Mr Driver. only at dead-ends and sharp bends in the line. Of late years on the Continent and elsewhere reinforced concrete poles are being employed, with, I believe, quite satisfactory results. Perhaps the author would give a few particulars of this type of structure—as regards its suitability or otherwise in connection with high-tension overhead transmission lines.

Mr. W. SLINGO (*communicated*): I am glad to learn that Mr. Slingo the work of the Post Office engineers is so much appreciated; and I venture to congratulate Mr. Welbourn upon the production of a paper which contains a vast amount of useful matter. There are a few points on which, however, I should like to make some observations. The first is on the question of wayleaves. He remarks that the Postmaster General possesses certain powers, which are described as being "so cumbersome as to be almost useless." Further on he asks for somewhat similar powers. Let me say that although the Post Office would like the procedure to be more certain and expeditious, the powers are nevertheless of considerable value. This is clearly demonstrated by the fact that apart from the lines acquired from the late National Telephone Company, and those which run along railways, the vast majority of the open lines are on public roads. The first Act of Parliament conferring such powers was passed in 1863, and several other Acts have since been passed to extend them; so that it has taken just 50 years to obtain the present powers, inadequate though they be. That being the case, and remembering that the telegraphs have been under the control of a State Department for 43 years, I fear that the task of such power engineers as may set out to secure statutory powers for their lines will be one which will tax their energies for a few generations. The Post Office might even object that the roads are likely to be inadequate to meet its requirements; but supposing that such a claim could not be sustained, the fact remains that the roads, particularly those leading to London and a number of the larger provincial towns, are now so fully occupied that there is little, if any, room left. The Post Office is already engaged in carrying out underground work along many of the highroads because of its inability to find room above ground. It is, however, somewhat difficult to understand why Mr. Welbourn should desire to utilize the roads unless it be that he desires the power as a lever to secure more moderate wayleave rentals. It is certain that owing to the sinuosities of the great majority of roads, more particularly of those minor roads which I imagine would be most likely those upon which pole lines would be erected, the extra constructional cost involved in the longer copper conductors would more than neutralize any saving which might be made on the wayleave account. But even in the matter of wayleaves I doubt whether there would be any saving. In the course of the discussion one of the speakers said that statutory powers were desirable because the capitalized wayleave rentals amounted in some cases to as much as £100 a mile. I am sure of this, that if such a rental value is not even an extreme case, but only an average case, any line erected under free wayleaves along the roads will involve wayleave rentals for stays and other strengthening fixtures in private property adjoining the roads, which will amount to at least a similar amount. The windings of the road

Mr. Slingo and the need for preventing accidents will be quite sufficient to account for this. Again, a long straight unstayed line is usually a weak one; the Post Office finds it necessary to stay such a line pretty freely, particularly if the ground be at all soft. The special advantages which road lines possess over field lines are the greater security of their tenure, the greater facilities available for their development and maintenance, and the better opportunities for their inspection; but all these can and should be bargained for in the course of the wayleave negotiations. I am afraid the risk of injury to life and property would be regarded as too great to permit of the erection of power lines along the roads. There would also be the risk of contact between the power lines and other conductors, telegraph, telephone, police and water circuits, etc. It should not be forgotten that while the risk of injury from the high-tension circuits to passengers proceeding along the road can be limited to a very brief period after a line has been blown down, the risk to the distant telegraph and other offices is continuous. The discharge may have lasted just long enough to set the place on fire, or it may have proved fatal to a number of operators who would have no such warning as a user of the road might be expected to have. Moreover it is not at all an unusual thing for a line to be blown over without either the poles or the wires breaking. In that case the danger would be even more prolonged. I fear, therefore, that the Post Office could not view with equanimity the prospect of parallel telegraph and power lines along the same road.

On the question of factors of safety Mr. Welbourn is inclined to criticize the factors adopted by the Post Office. Evidence that they are quite adequate so far as poles are concerned is provided by the fact that a pole is rarely broken. It should be borne in mind that a Post Office wire never exceeds $\frac{1}{4}$ in. in diameter and on main lines is usually somewhere between $\frac{1}{10}$ in. and $\frac{1}{6}$ in. On local lines the wires are still smaller. When these wires break they usually do so singly, and every one that breaks in this way reduces the risk of damage to the pole. The only occasion when the whole, or a considerable proportion of the wires, break simultaneously is when a tree falls across the line; no factor of safety, however high, is proof against such contingencies. When such an accident happens there is great risk of damage to the line for a considerable distance on either side, but this is avoided by keeping a good look-out for decaying trees, and by the fairly free use of longitudinal stays—stays, that is, in a vertical plane parallel with the vertical planes of the wires. The Post Office factor of safety of 4 for wires is usually found to be adequate, but in exposed situations it is the practice to increase the factor to 6. The principal cause of trouble is clinging snow; this only happens very occasionally. To increase the factor generally, as suggested by Mr. Welbourn, would mean that in the summer months the sag would be so great as to cause the wires, owing to a slight want in uniformity (such as might be caused by a joint), to come into contact, and without any consequent advantage, for when snow adheres and subsequently freezes and is then followed by wind necessary to cause destruction, a factor of safety of 20 would be insufficient.

The author assesses the life of creosoted poles at 35 to 50 years. I think he is too sanguine. He makes the saving Mr. Slingo clause that they shall be left undisturbed. Even in such circumstances 35 years is too long for an average figure, and when we take into account such contingencies as premature decay, compulsory removals due to wayleave difficulties, and inadequacy owing to the growth of the system, the effective life is more nearly 20 years. That at least is the figure arrived at by the Post Office, and covers several thousand poles, most of them erected on public roads. The Post Office has been in touch with Rüpingized poles for some years. It is too early to say yet whether the process is less effective than the Bethell process, but there are good indications that such is not the case. The process has, however, the advantage that the poles can be painted several years sooner than is the case with ordinary creosoted poles. The author advocates the slotting, etc., of the poles prior to the creosoting—no telegraph engineer would advocate such a policy. Apart from the fact that one never knows how many slots, etc., may ultimately be required, it should be remembered that poles are not turned out on a lathe, that they are not, even the best of them, symmetrical, and that it must always be left to the constructional engineer and his foreman to determine which way the pole shall stand in order that the line may be properly trimmed. I do not like the idea of tarring the lower portions of creosoted poles. It looks too much like the gilding of gold and the painting of lilies. It is neither useful nor ornamental. The author says that an angle (or "corner") pole should be so placed that the plane of the wires shall bisect the angle made by the wires; but this is of course only true when the spans on either side are of equal length.

Concerning aluminium, the Post Office experience is that owing to its lightness it is more liable than copper to be blown across the road. The possible advantages of aluminium in certain neighbourhoods are, however, worthy of closer attention. I have known copper wires to become so corroded in 18 months as to be incapable of supporting their own weight. It is doubtless well known to members that the strength of hard-drawn copper is little more than skin deep. Swinging into contact rarely happens if the wires supported by any one arm are of the same material and gauge and free from joints. In a heavy wind it is quite an ordinary thing for the wires to be blown into a horizontal plane. The great advantage of white insulators is that it can easily be seen whether they are clean or foul. All forms of dirt become fairly good conductors, particularly in damp weather, and the loss from this cause may easily be very appreciable.

Professor E. W. Marchant (*communicated*): On page Professor Marchant 181 the author describes a graphical method for finding the losses in the line. A much simpler way of calculating them is to find the current in the line and the resistance of each line, and from these to calculate the power lost. A graphical method is convenient for estimating the pressure-drop on the line, but even in this case it is quite as easy to calculate the drop. I wish the author had conformed with the recommendation of the International Electrotechnical Commission and drawn his diagram in Fig. 3 so that the vectors rotate counter-clockwise. The equation for the breaking stress in tons per square inch, $T = 30 - 20\,D$, must obviously be limited in its application,

and it would be useful if the author could give us the range of values for which the formula holds.

With regard to aluminium lines, the practice in America seems to tend towards the use of copper. Aluminium is never used near the sea on account of corrosion. It is a metal of very variable qualities and it appears to be difficult to find specimens which will behave in a perfectly uniform way. Professor Wilson described at the meeting of the British Association some results which he had obtained at King's College with commercial aluminium exposed to the atmosphere. One interesting point is that the variation in resistance in specimens first exposed 2 years ago is greater than it was 12 years ago when the atmosphere was much more smoky. This result is probably due, as he points out, to small variations in the impurities in the metal. I do not understand the reason for the difference in spacing recommended for 20,000-volt and 10,000-volt lines. Electrically there is no reason why the distance between them should not be 3 in. instead of 3 ft. at 20,000 volts. The only factor which has to be considered is the risk of the wires touching, and this is as likely to occur on a 20,000-volt line as on one working at 10,000 volts. The rule mentioned by Mr. Peck of 1 ft. spacing for every 10,000 volts, with a minimum distance of 2 ft., seems to be quite satisfactory. Very little trouble has been experienced due to the swinging together of the wires, even on long spans. In this connection I may mention that the longest span I have seen is one of about 3,000 ft. across the straits just outside San Francisco. Steel wires had to be used in this case in order to provide adequate strength. The question of pin versus suspension-type insulators is almost entirely an economic one, and I am inclined to think that the suspension-type becomes cheaper at a considerably lower pressure than the author suggests. The limit which I have found with the figures at my disposal is about 30,000 volts. With regard to the use of Moscicki condensers as lightning arresters, I should like to ask whether any trouble has been caused by static charges. The condenser provides no path for the static charge and under heavy atmospheric disturbance might easily be broken down.

Mr. B. WELBOURN (*in reply*): I should like to thank the various speakers for the cordial reception which they have given to this paper, and I am pleased that the discussion has brought out such a number of practical points and so much useful information. The suggested alterations in phraseology, etc., which come from Mr. Donkin are good and I must ask members to be good enough to alter their copies of the *Journal* as the paper has already been printed. In Appendix VIII the coefficients of expansion of aluminium should be corrected to read 0·0000245 and 0·0000136. The printers have my sympathy in the difficulty of setting up such large numbers of figures.

The discussion in London and at the provincial centres will have demonstrated to the Council of the Institution that there is a genuine grievance on the part of statutory undertakers in regard to wayleave difficulties, etc. As Mr. Woodhouse says, the subject has been ventilated before the Institution for several years without any assistance from the Council being forthcoming. The task of persuading the Government to attempt to alter inconsistencies in the law of the wayleaves, etc., and to put statutory and non-statutory undertakers on an equal footing, is one which the Council might well deal with, instead of leaving the matter to be fought out by a few power companies. Representations on the subject would come with greater force and authority from this Institution speaking on behalf of several thousand members.

Mr. Welbourn.

Mr. Slingo's remarks on wayleaves come very opportunely and indicate clearly the difficulties to be faced. It is probable that the "spade-work" already done during the last 50 years by the General Post Office will be of the greatest value to this Institution if the Council decides to deal with the matter. There can be no doubt that they would welcome Mr. Slingo's co-operation and would be glad to have the benefit of his great experience. I am glad of the opportunity afforded to me by Mr. Slingo and other Post Office engineers of explaining that the wayleave difficulties referred to are those in connection with "work across country," as stated in the context. The local authorities afford many facilities to the Post Office for the erection of lines along roads, and I do not suggest that high-tension lines should be run except under very unusual circumstances along roads already occupied by the Department's wires. There are many difficulties in erecting lines along roads, but the privilege of being able to use the roads for high-tension lines would sometimes be of the utmost value for "short-circuiting" difficult landowners and for giving a supply to outlying farms, etc. It is suggested that this matter (among others) might be dealt with by appointing a Transmission Lines Committee who would advise the Council on all matters affecting overhead lines and who would draw up a report on the immediate difficulties and proposals for dealing with them. I feel sure that it will be gratifying to Mr. Trotter to learn from the discussions in London and the provincial centres that practically all the engineers who are responsible for the operation of high-tension lines are satisfied with the factors of safety prescribed in the present regulations of the Board of Trade. I am inclined to think that if these are ever revised and put on a more scientific basis they will be based, as far as the conductors are concerned, on the limit of proportionality and not on the ultimate breaking stress. This is equally fair for copper and aluminium.

I was very interested indeed in what Commander Schwann said with reference to airships. From the supply authority's point of view there is an obvious answer to the attitude of the Admiralty, *i.e.* that the supply authorities would be delighted to put all their high-tension wires underground if that Government Department would give them a subsidy that would recoup them for the extra cost. This question of damage to aeroplanes and airships by high-tension wires is a new point to us, and a method of indicating their position will require very careful consideration; possibly when we have had time to think it over we shall be prepared to make suggestions which will go some way towards meeting the Admiralty's views. The solution will be difficult if provision has also to be made for indicating pole routes during the hours of darkness. I think that possibly some restrictions will have to be imposed in regard to the erection of any overhead lines, especially high-tension lines, within a radius of, say, 5 miles of Government air stations on the coast. We must all be prepared to place patriotism before other considerations, and not to do anything which will in any way interfere with our national safety.

Mr. Welbourn.

Mr. Woodhouse and other speakers have raised the question of the cost of overhead lines and wayleaves. The latter aspect of this was dealt with by Mr. Vernier in his remarks. Figures as to cost are necessarily general, and will vary according to local conditions. Figures supplied to me show that across difficult country where haulage and wasted walking time are large items of expense the first cost of a line, such as that for which figures are given in the paper, has been as much as £1,600 per mile. I think, however, that my figures represent average conditions. They indicate that the principal savings are to be made in using overhead construction where the voltage and the kilowatt capacity are high. Mr. Vernier supported the view which I interjected into my opening remarks, that at 3,000 volts the saving to be made by using overhead construction in preference to underground cables is frequently insufficient to make it justifiable commercially. The same remark also applies to some of the low-pressure overhead schemes which have been carried out.

With regard to conductors, I have tried to make it clear in the paper and by explanatory remarks that at our working pressures (into which corona questions do not enter) the total overall cost should determine the choice between copper and aluminium. I quite recognize the force of the remarks on this point and I agree that the advantages and disadvantages must be fully weighed in each case, always bearing in mind that a small increase of reactance on overhead aluminium lines is not wholly a disadvantage in that it helps to limit the effects due to the failure of insulators, etc.

Mr. Jacob called attention to a recent article in the *Electrical Review* on the Rjukan Foss scheme in Norway, in which the statement is made that aluminium conductors when kept alive do not gather snow. This question of the collection of snow by copper and aluminium was discussed before this Institution two or three years ago when two papers dealing with American practice in overhead lines were read;* and in his reply Mr. Borlase Matthews was emphatic that American experience showed that aluminium and copper collect snow equally. I welcome this statement in the *Electrical Review*, coming as it does from a reliable authority. On the other hand, there is reliable evidence that the aluminium conductors on the Sherburn lines in Durham did collect sleet even when kept alive. Possibly the aluminium-producing companies will consider the desirability of engaging an independent expert to experiment on this question. I would suggest that investigations should be carried out with aluminium and copper wires which have been erected for some years, as well as with new wires.

I regret I cannot agree with Professor Marchant that aluminium is never used near the sea on account of corrosion. I looked into this matter rather closely last year and came to the conclusion that the corrosion of aluminium is usually to be associated with the metal in the form of an alloy not protected from air and moisture, or else with the presence of excessive quantities of impurities. The aluminium which is used for British overhead lines usually contains not less than 99·30 per cent of pure metal, and I should not hesitate to use it near the sea. I shall be pleased to show Professor Marchant a sample of aluminium wire which is in my possession after being in use near the coast for about ten years. As stated in the paper, our knowledge of the production and working of aluminium has increased rapidly during the past three years. It is this knowledge which has led me to doubt the present commercial value of the interesting tests which Professor Ernest Wilson has carried out at King's College. I am well aware of the character of the smoky atmosphere above the College after spending more than three years of my student life there, and I am glad to think that no aluminium or copper is likely to be erected on high-tension lines in this country where it would have to meet such severe conditions. It would be very useful if Professor Wilson would repeat his experiments in country air and publish the results.

Mr. Welbourn.

Professor Marchant and other speakers have queried the minimum spacing of conductors suggested on page 185. These minimum spacings are founded on no general law, but on a considerable amount of experience in this country and elsewhere, and are mainly determined by the sizes of pin insulators and the clearances necessary at the points of support. Examples of spacings found necessary on various lengths of span in this country have been given on pages 182–3. A good deal of experience is required to settle the spacing necessary in each case.

The equation $T = 30 - 20\,D$ for the breaking stress of copper in tons per square inch is applicable to all the sizes of wires in Appendix IX. For a full treatment of the subject reference should be made to Mr. D. R. Pye's paper on "The Mechanical Properties of Hard-drawn Copper," which is mentioned in the Bibliography on page 194 of my paper. I am sorry that it is too late to adopt Professor Marchant's suggestion that I should alter Fig. 3, as the number of the *Journal* containing my paper has already been issued.

I am much obliged to Mr. Trotter for pointing out an apparent inconsistency in connection with the glaze of insulators. The first reference is to rigid clamps breaking the glaze and causing insulators to fail *some years ago*. In the period which I had in mind, the importance of having high-tension insulators vitreous throughout was not always recognized, and too much depended on the soundness of the glaze. I showed such an insulator at the meeting. The necessity of complete vitrification is now well understood, and emphasis is laid on it in the paper. Attention to this point and to that of colour, coupled with the tests set out in Appendix XII, should give quite satisfactory results.

Mr. Kay showed a series of slides of the special steel pole which his firm is developing. It is a very interesting type, and I wish it success, but I fear it does not escape some of the objections which I have urged against steel if it is intended for use in districts where smoke and other corrosive agents exist. Special precautions are needed to preserve the steel stay wires on which so much depends in this design; and one also wants to know how the interior of the steel members is to be prevented from rusting. The external painting of steel poles every two or three years is a serious item of expense, and, in addition, the supply of energy must be interrupted while the tops of the poles are being done. It is difficult to imagine this or any

* W. T. TAYLOR. "Modern Long-distance Transmission of Electrical Energy." *Journal I.E.E.*, vol. 46, p. 510, 1911.
R. B. MATTHEWS and C. T. WILKINSON. "Extra-high-pressure Transmission Lines." *Journal I.E.E.*, vol. 46, p. 562, 1911.

other tubular steel pole having the life of a well-creosoted wood pole until the all-electric era is with us, and smoke, etc., are banished. I will readily agree with Mr. Kay that he is making provision for some of the obvious difficulties; but when I compare his strong recommendation of high-tensile steel with the equally strong condemnation of it which comes from Mr. Fox (a steel-tube manufacturer), I am more than ever convinced that it is difficult to make out a good case for steel poles (lattice or tube) in most parts of the United Kingdom. Of course steel or wrought-iron structures must be used on railways, etc. It is a case of *force majeure*; but the bridges, etc., are a source of constant worry to the engineers who are responsible for their upkeep, and the frequent cleaning and painting are very costly. Evidence of this dissatisfaction with steel is forthcoming from the increasing use of ferro-concrete structures. Poles of this material have been used for some low-tension lines in this country; and while I do not know of any high-tension line employing them, I think they are certainly worthy of serious consideration. Mr. Fox has asked me a question about roof maintenance. This is not directly comparable with pole—and especially tubular pole—maintenance. In one case we are considering corrugated iron which presumably starts its career with a new coat of galvanizing, and yet requires to be painted externally every two years. In the case of lattice steel poles, the two-year cleaning and painting are just as necessary, while tubular poles cannot even have this attention inside—I do not think anybody will dispute that they need internal attention despite the original coating of Angus Smith's solution. I should say that Mr. Fox's roof is satisfactory to him because of the original galvanizing and the frequent coats of paint. It would be instructive to know what this has cost.

Mr. Morton's contribution is particularly acceptable in so far as it discusses the question of the factor of safety and its bearing on practical construction work and design. A full consideration of the inner meaning of the lantern slides showing snow-covered conductors, and a knowledge of the effects which have resulted during a gale, have led me to the conclusion that no case can be made out for reducing the Board of Trade's prescribed factors of safety for overhead conductors on high-tension lines on which continuity of supply is usually more important than a possible saving of a small percentage in the first cost. It also follows that where continuity of supply is the paramount consideration, *e.g.* the supply to a city such as London or to any big town, or even to an electrochemical works, the transmission line must consist of duplicated underground cables, which are exceedingly reliable and can be protected against mechanical injury. Although the question of reducing the factors of safety on low-tension lines does not immediately arise on this paper, I am in sympathy with his argument so far as it relates to them. The problems and dangers on high-tension and low-tension lines are not the same in every particular.

I agree with Mr. Nelson that factors of safety might form the subject of a paper. May I suggest to him that he should undertake it? I think he might find that for high-tension work a better case could be made out for raising than for lowering them. He has made a good point as to the advisability of using side stays for preventing the swinging together of the conductors in certain cases. Fig. 14 was intended to be diagrammatic and I agree that the leakage path should in practice be as long as possible. Four insulators at transposition points may be, and frequently are, used, but the arrangement is not so neat as that shown. The final choice must depend on the local conditions, as in many other features of overhead-line construction. Mr Welbourn

I welcome Mr. Stubbs's and other communications which have only reached me in time to receive brief treatment before my reply is published in the *Journal*. Mr. Stubbs has given us the benefit of the extensive experience of the Post Office, and his points will be carefully noted by transmission line engineers. I may explain that the 3/5 factor is that stipulated by the Board of Trade, and it was probably settled in conjunction with the prescribed factors of safety. The length factor for the steel channel had not been overlooked. The formulæ can be used for channels as shown in Fig. 6. Mr. Stubbs' point as to guarding was partly dealt with by Mr. Trotter. While a good deal of guarding might be abandoned, it was not my intention to suggest that there should be no form of guard where high-tension wires and telephone or telegraph wires are in close proximity. I take this opportunity of correcting an inaccuracy on page 192 of my paper. The times mentioned for the operation of the Merz-Price and Merz-Hunter systems refer to the times required for the operation of the relays which control the switch-tripping-device. The latest types of high-tension switchgear will open the circuit in 1/25 second after the relay operates. Even with the addition of this time, it is inconceivable that a fallen high-tension wire could reach the ground before becoming "dead" with the Merz-Hunter system, and it is certain that no synchronous plant on the system would have time to fall out of step with that or the Merz-Price system.

Mr. Driver's remarks are outside the scope of the paper, but his reference to foreign practice is nevertheless very interesting. I do not think anybody would erect 1·0 sq. in. aluminium conductors on a high-tension overhead line, but it has been done on low-tension lines with considerable saving in cost when compared with copper.

Mr. Brazil joins issue with me over the question of line protection by apparatus involving the use of a spark-gap (or an arc gap). The discussion has shown that my views are shared by engineers who have had considerable experience in the operation of overhead high-tension lines in this country, and who have given much thought to this admittedly difficult problem of protection. I refer particularly to Messrs. W. B. Woodhouse, C. D. Taite, P. V. Hunter, and C. Vernier. I am aware that horn arresters have been extensively used with apparent success on low-tension overhead systems for many years, but this result has in my opinion come about in spite of the arresters, and is due to the inherently high factor of safety on these systems. Reference to the test pressures in Appendix XII shows that when dry there is an approximate factor of safety of 15·3 on a 3,000-volt insulator and only 5·25 on a 20,000-volt insulator; these become 9·0 and 3·7 respectively under the spray test. On low-pressure systems the factor is still higher. I think our President, whose Address we both quote, has shown by oscillograph tests that the highest pressure rise which he has found on an alternating-current circuit is not more than 4·4 times the working pressure. This has led me to the conclusion that far more damage is done by high-frequency disturbances

Mr. Welbourn

than by surging at the intended frequency of the supply circuit. The increased pressure accompanying these disturbances is frequently insufficient to cause the horn arrester to discharge, and so it does not meet this difficulty.

Dearly-bought experience in some districts in this country has caused the discarding of horn arresters. When they spark (or arc) over, they are themselves starting fresh high-frequency oscillations—the very thing which it is desirable to avoid. I think it is not unfair to inquire why horn arresters have been so gradually discarded on high-tension lines in the United States and Canada in favour of electrolytic aluminium arresters and other devices. One speaker has pointed out in the discussion that the horn arrester is an objectionable feature of the aluminium arrester. An American investigator has shown that the horn arrester has a time-lag, and that it is possible for a pressure front to pass it before the arrester can act. In concluding my reply to this most interesting contribution from Mr. Brazil, may I also quote our President's dictum that "any arcing or sparking taking place in a circuit is liable to set up oscillations which may give rise to dangerous pressure rises," and mention that porcelain insulator makers are turning their attention to the design of insulators which will withstand these high-frequency effects.

In reply to Mr. Trechmann, some transformer makers now employ the specially-insulated end-turns as their standard practice whether the transformers are for use on overhead lines or not, and therefore the question of extra cost does not arise. As regards regulation, in practice the regulation of a transformer is settled by the maximum short-circuit current which the makers can allow to pass through it. The additional insulation has no effect in practice because the maker purposely makes the regulation worse than would be the case if he were neglecting this question of short-circuit conditions. I am inclined to agree that the number of end-turns to be reinforced would probably be less than 10 per cent as working pressures are increased above 20,000 volts, alternating. At and below that voltage, the 10 per cent arrangement seems to be quite satisfactory.

I have not heard of any trouble from static charges on 20,000-volt lines in this country, or of any resulting trouble with Moscicki condensers, which are now being made for working pressures up to 45,000 volts, alternating. The number of condenser tubes to be installed is settled largely by experience after inquiry into the local conditions. It is conceivable that all the fuses might be blown during an exceptional thunderstorm. Where static charges are to be feared on an overhead line it is advisable to make provision for their dissipation. This may be effected—

(*a*) By earthing the neutral point of the system.
(*b*) By earthing each conductor through an impedance coil or through a high resistance.

I know that Mr. Paton had some unfortunate experiences several years ago with flexible binders and I do not wonder that he is prejudiced against them. I have made close inquiry as to the behaviour of the flexible binder shown in Fig. 8 and find that over a period of seven years and with experience of several thousand binders, only one binder has stretched and had to be replaced. This occurred at a corner pole. Both with this and with Mr. Paton's semi-rigid binder, experience in fixing and good workmen are essential. In fact much experience is needed throughout in design and erection to obtain a successful high-tension overhead line. The question of abrasion with this flexible binder has also been looked into and there is no evidence of it in one of the most exposed districts in England.

I particularly wish to thank Mr. Wigham for the loan of the Cornwall slides. They have been much appreciated at the Local Section meetings. The artistic design of the sub-station has called forth favourable comment, and it is to be hoped that the design will lead to improvements elsewhere.

As questions have been asked about the use of the "drop-factor" method given on page 181, I give the following notes with examples of its use in the hope that these may make the method quite clear:—

The tables in Appendices III and IV are for single-phase lines, but they can be used for three-phase lines by taking half the three-phase load and calculating as if it were single-phase. For example, assume that 50 kw. are to be supplied at a pressure of 1,000 volts, single-phase or three-phase, at the point of delivery. The power factor is 0·95; the length of line is 2,000 yards; the conductors are No. 1 S.W.G. copper; the periodicity is 60 cycles per second; and the spacing between the conductors is 12 in. Then the two cases are as follows:—

Single phase.—The apparent kilowatts $= 50 \div 0{\cdot}95 = 52{\cdot}6$; $\therefore$ current $= 52{,}600 \div 1{,}000 = 52{\cdot}6$ amperes.

From Appendix III the resistance per 1,000 yards of No. 1 S.W.G. copper wire $= 694$ ohms. $\therefore$ Voltage lost in the resistance $= 2 \times 0{\cdot}694 \times 52{\cdot}6$, *i.e.* 73 volts.

Again, from Appendix III the ratio of reactance to resistance with 12-in. spacing at 60 cycles is 0·92. In Appendix IV this ratio comes between 0·9 and 1·0, and at 0·95 power factor is equal to 1·252, so that the total drop in pressure is $73 \times 1{\cdot}252$, *i.e.* 91 volts.

The impressed voltage would therefore be $1{,}000 + 91 = 1{,}091$ volts.

Three phase.—In this case the apparent kilowatts are one-half of the total apparent kilowatts, *i.e.* 26·3 ($52{\cdot}6 \div 2$). The current is $26{,}300 \div 1{,}000 = 26{\cdot}3$ amperes, which is equivalent to the current in a single-phase circuit delivering half the output with the same percentage pressure-drop as occurs in the three-phase circuit. Working this out as in the above single-phase example, we obtain—

Voltage loss in resistance $= 2 \times 0{\cdot}694 \times 26{\cdot}3 = 36{\cdot}5$ volts.
Total voltage loss $= 36{\cdot}5 \times 1{\cdot}252 = 45{\cdot}5$ volts.

The impressed voltage would therefore be $1{,}000 + 45{\cdot}5 = 1{,}045{\cdot}5$ volts.

It should be noted that the resistances in Appendix III are given for a temperature of 60° F., and that the necessary corrections should be made for the resistance at other temperatures. By the above method the size of wire for a given pressure-drop can also readily be found with a little practice.

Birmingham Local Section, 7th January, 1914.

Dr. Garrard. Dr. C. C. Garrard: The principal data at present available on this subject come from America. A study of the papers presented to the American Institute of Electrical Engineers would indicate that the chief difficulty at present over there is the so-called corona loss which limits the transmission voltage. The different conditions which prevail in this country are illustrated by the fact that this subject is not mentioned in Mr. Welbourn's exhaustive paper. We may take it, I presume, that for some time we shall not have in this country to any large extent transmission lines operated at pressures higher than 20,000 volts; I should like, however, the author's opinion on that point. I can emphasize the necessity of galvanizing insulator pins. In a certain instance which came under my notice the insulator pins were not galvanized and were fixed into the insulators by litharge cement. Continual trouble was experienced, due to the insulators cracking, which was finally traced to small quantities of rust forming on the pin. Galvanizing got over the trouble. I should like to ask whether the author finds litharge cement suitable for fixing insulators on their pins. I note that the author recommends cast-iron earth-plates. I have been under the impression that copper earth-plates were better practice, but if cast-iron ones are quite satisfactory they are much to be preferred owing to their cheapness. With regard to the protection of lines against atmospheric disturbances, the author states that even at pressures of 20,000 volts there is no need to make provision for protection against lightning where a cable is "teed" on to an overhead line. This is most important, as the opinion has been put forward that some form of protection is necessary. I should like to know, however, whether the author's statement is confined to paper-insulated cables only, or whether it also applies to any other kind of cable.

I do not agree that horn arresters can only relieve a surge voltage by 20 per cent of its value. If this statement were true, horn arresters would be of no use whatever—a conclusion difficult to reconcile with their large and continued use. It is quite true that they are a somewhat crude method of protection, but on the other hand they are very cheap. If expense is no object a much better system of protection can be installed either by means of Moscicki condensers or aluminium cells. I do not agree that the resistance in series with a horn arrester should limit the current to earth to 10 amperes. The resistance should be about 50 ohms, which on a 6,600-volt three-phase line, with neutral earthed, would give a current of 76 amperes. To deal with such a current a liquid resistance should be installed rather than a carbon rod. Steinmetz has also shown that with such a horn-gap and a series resistance—and of course a choking coil—installed at the transmission station a pressure higher than 50 per cent above the normal cannot enter the station. A general condemnation of spark-gaps in connection with arresters is, in my opinion, not permissible. The aluminium lightning arrester, which has been used extensively in America, although originally invented in this country, has a spark-gap. Excellent results are claimed for this arrester, and I believe the claims are justified. The Giles valve, which is made by the manufacturers of the Moscicki condenser, also employs spark-gaps, and I believe it gives very good results in connection with the protection of machines. As regards the use of condensers for protective purposes, I have no doubt that theoretically they are perfectly correct. Moreover, they have been widely used, especially on the Continent, and experience has shown that they have given satisfactory results where all other systems have failed. In Fig. 12 six condenser elements are apparently shown per phase. In series with each tube is a fuse, which blows, I believe, when a discharge takes place. It would be very interesting if the author would state whether there is any danger of all the fuses blowing during a severe thunderstorm and leaving the power station unprotected. I should also like to refer to the very short times within which it is stated in the paper that certain protective devices remove faults from the line. In the first place I presume the times given are those within which the device begins to operate, as no automatic switch could complete its operation in so short a period. Also I am doubtful whether such a very short period is desirable owing to the heavier duty thereby imposed on the oil switch. It is found that the short-circuit current is very much larger in the first instant than it is, say, one second after the short-circuit comes on. With the continual increase in the size of generating and distributing systems the breaking capacity of the oil switch becomes a limiting feature, and it is therefore important that an instantaneous disconnection of a short-circuit should not be possible.

Mr. Moffett. Mr. F. J. Moffett: The present state of the law in regard to wayleaves is an anachronism, and is a very serious handicap to electrical development generally. It is the duty of the Institution to see that in the matter of legislation we in this country should be freed from such disabilities and placed on a level in this respect with other European countries, if not with the United States. I agree with the author that wooden poles properly treated with creosote are the most suitable for all positions except where appearance is a consideration. A few years ago I examined some poles which had been erected over 40 years, and which were being removed to allow of heavier poles being substituted. They were in very good condition, including the part below the ground. In many industrial districts, such as the Black Country, the air is so laden with acid that the life of iron or steel is short unless care is taken to coat it periodically with some preservative such as coal-tar or bitumastic paint. Some years ago a process for the construction of poles of reinforced concrete was brought out. Such poles should have a long life, but do not appear to have come into use to any great extent. I should like to hear whether the author has had any experience of them. Since aluminium has been produced with so much smaller a percentage of impurities than was the case a few years ago, it appears to be much less liable to corrosion under most conditions, and is now in this respect as satisfactory as copper. The chief drawback to its use is the difficulty of making a good electrical and mechanical joint. The twisted sleeve joint is simple and fairly satisfactory; the two ends of the cable to be jointed are inserted side by side in a sleeve which is

Mr. Moffett. then given some six complete twists. In my experience of overhead construction I have found that the most effective method of tying in the line wire is first to cover it with a lapping of soft copper tape and then to tie it in with a soft copper binder. I do not agree with the author in his dislike of any form of lightning arrester involving a spark-gap. Several years' use of Wurtz multiple-air-gap arresters on overhead lines has convinced me that they form an efficient protection. These lines were erected in Nigeria, a part of the world where thunderstorms are much more violent and frequent than in this country. No choking coils were used in connection with these arresters, but no damage was ever done to machine windings or switchgear.

Mr. Mountfort. Mr. L. F. Mountfort: As I am responsible for a high-tension transmission line in the immediate neighbourhood I naturally welcome this paper very heartily and I feel sure that this subject will become in the future of increasing interest to us in this country. Referring to the comparative costs of overhead line and cable given by the author, I should like to know whether the poles are ordinary single poles or A-poles, as the cost of the line seems to me unnecessarily high. In the Appendix the author gives a table of "drop-factors" for calculating the voltage loss in transformer lines. I should like to suggest that we might have a table that would give us this information directly in terms of the size of wire and would be subject to no greater errors than are involved in the author's table, to which he refers and which are as he remarks, practically negligible. In order to make this clear I put forward the following table, which is one that I have found very useful in transmission-line work. This table shows very clearly the small effect which the employment of large sizes of wire has upon the pressure-drop, especially at lower power factors; and the great advantage in this respect of installing at the receiving end of the line apparatus such as synchronous machines capable of taking a leading current.

Three-phase Transmission. Voltage Drop between Lines per 1,000 Ampere-yards (route length). 50 Periods. 3–5 Feet Spacing

S.W.G. Copper Line Wire	Power Factor Lagging							Power Factor Leading			
	0·60	0·70	0·80	0·85	0·90	0·95	1·0	0·95	0·90	0·85	0·80
8	1·77	1·95	2·07	2·13	2·15	2·16	2·07	1·80	1·63	1·48	1·34
7	1·52	1·68	1·77	1·78	1·80	1·81	1·72	1·49	1·34	1·20	1·09
6	1·38	1·48	1·54	1·56	1·57	1·57	1·46	1·25	1·10	0·98	0·87
5	1·22	1·28	1·32	1·33	1·34	1·32	1·20	0·98	0·87	0·75	0·65
4	1·09	1·13	1·15	1·16	1·15	1·13	1·01	0·80	0·69	0·58	0·50
3	0·98	1·01	1·02	1·01	1·00	0·98	0·86	0·66	0·55	0·45	0·37
2	0·89	0·91	0·91	0·90	0·88	0·85	0·73	0·54	0·43	0·34	0·27
1	0·81	0·83	0·82	0·81	0·78	0·74	0·62	0·44	0·33	0·26	0·19
1/0	0·76	0·76	0·75	0·74	0·71	0·66	0·54	0·36	0·26	0·18	0·12
2/0	0·72	0·71	0·69	0·67	0·65	0·60	0·47	0·29	0·20	0·12	0·06
3/0	0·69	0·67	0·66	0·64	0·61	0·56	0·42	0·25	0·16	0·08	0·02
4/0	0·64	0·62	0·60	0·58	0·55	0·49	0·35	0·17	0·09	0·02	−0·04

I am surprised to hear that the author does not believe there is any necessity for placing the aerial earth-wire above the power wires as a protection against lightning. I think that it is decidedly useful in this respect, although I agree that it should be of the same material as the power wires, not only on account of its longer life but also on account of its greater conductivity. I am sorry the author has been so severe in his condemnation of spark-gaps. Our 6,000-volt lines are protected with arresters of the "multi-gap" or "low equivalent" type where they enter the sub-station, and choking coils of wrought iron are placed in each line. This apparatus has given no trouble since its installation, and spark-gap arresters are installed in all the sub-stations on the 2,000-volt system. It seems probable that the spark-gap arrester finds its chief usefulness in systems of moderate voltage—6,000 to 10,000. Beyond these pressures the number of gaps required makes the apparatus somewhat cumbersome and it would probably be better to employ the electrolytic or other form of condenser arrester. It is interesting to hear that in the author's experience it is not necessary to install any form of protective device at the point of junction of cables and overhead lines, as this has always hitherto been regarded as advisable in order to protect the cable from atmospheric disturbances. With regard to the method of protecting the apparatus in the station by placing extra insulation on 10 per cent of the windings on the line side of the transformers, there does not appear to be any reason why a fixed percentage of the end turns should be reinforced in this way. This would appear to depend upon the voltage of the supply, as a transformer of comparatively few turns would probably have the impact stress of a surge distributed over most of its windings, while one of many turns would only be stressed through a small percentage of its windings. One objection to this method of protection appears to be that it protects the station but not the line, and as a punctured insulator generally means a shut-down it would seem advisable in cases where continuity of supply is important to install some form of protection for the line as well.

Mr. Welbourn. Mr. B. Welbourn (*in reply*): Many of the points which have been raised have already been dealt with in my reply to the London discussion, and I would ask members to refer to it. Dr. Garrard referred to the question of the raising of working pressures. As I stated in the paper, my belief is that we are now on the eve of the raising of

working pressures above 20,000 volts (alternating current) in this country. This seems inevitable in view of the increasing transmission distances and the larger number of kilowatts to be transmitted. I have had no experience with litharge cement, but I have come across cements which have swelled after a few years' use and have burst the insulators. This is one of my reasons for preferring pins fixed with tarred yarn. The statements about the use of cable for connecting up a high-tension line applied to paper-insulated cable. It has been proved everywhere that this type of cable is the only one which will withstand high-tension working conditions out-of-doors. I am exceedingly pleased that Mr. Mountfort has given us the table which he has found useful from experience. One of the features of these discussions is that so many useful points have been brought out.

DISCUSSION ON

"ELECTRICITY SUPPLY OF LARGE CITIES."*

Scottish Local Section, 9th December, 1913.

Mr. F. A. Newington: I am afraid Dr. Klingenberg's address is rather a difficult one to discuss. The author has taken three cities which he considers typical. I do not know what he means by that—whether typical of the countries they represent or not—but I think that London is the very worst example that could be taken in this country, because electricity supply started in London in the very early days, and the Government allowed London to be divided into a large number of small districts, each to be supplied by one or two undertakings. The object was to prevent such a monopoly as exists in the case of gas. Now we see that it was a great mistake; but at that time it was thought to be the better plan. By dividing up London in that way it has become impossible to have a general supply from a few large centres. The author assumes, or at least suggests, that it might be possible to do away with the whole of the present stations and to build large new central stations, but I do not know how he is going to get over the difficulty of the large capital expenditure that has been incurred, which is, I believe, over £3,000,000 sterling. He says the existing mains would do, but that all the generating plant would have to be scrapped; I suppose that represents a sum of between four and five million pounds. How is interest to be paid on that capital? Towards the end of his address he mentions that the paying-off of this debt has been allowed for, but he does not show how. I think that debt would very much outweigh the benefits of the large new generating stations. Berlin seems to be very fortunate in that respect. It had a very large number of private plants apparently merely supplying electricity to blocks of buildings, and when the larger stations were started I suppose some of the small private stations were shut down, but there was no question of having to buy up these undertakings. In Chicago it seems that the old undertakings were purchased at an outlay of 10 or 15 per cent of the cost of the new works. That is an extremely low price, and the company were very fortunate in being able to buy up the old undertakings so cheaply. I suppose the undertakings had not developed very far at that date. Of the three cities selected for comparison, I think it is a pity that London was chosen. Manchester or Glasgow would have compared on more equal conditions with Berlin and Chicago. It must be remembered that the London companies are in no way to blame for the existing state of affairs. They were each allotted their small area, and were not allowed to combine, and their life was limited from the very beginning. Dr. Klingenberg's address might be of value 15 or 16 years hence, when the London County Council will be considering the purchase of all the present undertakings.

On page 125 the author recommends the transmission of 10,000 kw. through one cable. With the present Board of Trade regulations that of course could not be done in this country. He also refers to a 20 per cent loss in transmission in the other systems. With continuous-current systems at any rate that is far too high a figure—7 or 8 per cent is much nearer; and I think in a city of reasonable size, that is if the city is not too large for a low-tension supply, the low-tension loss must be less than the high-tension loss with transformation. With the long distances discussed it must of course be high-tension, but the loss will be greater. On page 127 the author mentions a load factor of 50 per cent for power and 50 per cent for traction; 50 per cent seems far too high a load factor for power—it means that the works are operating at their full output for 12 hours a day. A much more likely figure is 20 to 25 per cent. Again, 50 per cent also seems too high for traction. I think 30 per cent would be nearer the mark. These figures will make a considerable difference to the author's calculations. The most important point in a matter of this sort has been left out, namely, the selling price. So far as I can see there is no mention of price per unit sold except on page 131, where the author says the selling price in London is 13 per cent lower and in Berlin about the same percentage higher than the normal value. Does he take Chicago as the normal? If so, London is not doing so badly.

Mr. S. Mavor: I think there can be no doubt whatever that in large cities the association in the same power station of generating plant for lighting, power, and traction, is the correct policy; the economies to be derived therefrom are well brought out in Dr. Klingenberg's address.

* Address by Dr. G. Klingenberg (see p. 123, No. 225).

Mr. Mavor. The figures given for the ratio of the stand-by plant to the peak load appear to me to be very high. They surely cannot refer to the whole generating plant, including boiler equipment. Even if merely the generators are included, the figure of 40 per cent seems to be extremely high for stand-by plant; and even 25 per cent seems to be high for large plants unless the individual units are very large. The size of the individual unit must have a bearing on the size of the stand-by plant; if a station with a capacity of 100,000 kw. contains only units of 25,000 kw. capacity it cannot do with less than one set spare, equivalent to 25 per cent; but in smaller stations with smaller units a less margin than 40 per cent should be adequate. I think the whole subject must remind us of the prescience of Dr. Ferranti in his bold conception of the Deptford station; this station unfortunately did not realize the early anticipations, largely because the generating plant of the requisite magnitude was not available. Like Mr. Newington, I miss any direct reference to the selling price, which is, of course, a very important factor in the whole question. I do not know what the selling prices are in Berlin, but I think the prices in Glasgow are lower than in any other city of which I have heard. In my own case, for domestic supply through one meter the average cost for lighting, heating, and other purposes only amounts to between 1¼d. and 1½d. per unit. It is perfectly certain that with such a cheap supply the development and use of electricity for all kinds of domestic and industrial purposes must go ahead very rapidly.

Mr. Spence. Mr. W. L. Spence: If the author's basic data are accepted, and I think it is unreasonable to assume that he would found his paper on data which could not be substantiated, points of very great importance are brought out. I refer particularly to the influence of combined load factors in reducing the cost of supply. The load factors given are :—light 18 per cent, power 50 per cent, traction 50 per cent, and it is shown that the combined load factor is not sensibly below that due to power and traction only. This is of very great interest, because it is not our general practice so to combine all three supplies. From the traction point of view alone it may be admitted that the advantages of combination are not great, but in any case a reduction of a few per cent in the traction-supply costs is of no particular value, because electrical energy is a very small proportion of the total operating expenses. The traction output is independent of the costs, so that a reduction in the costs brings no increase in the demand. Above all, nothing should be done to encourage further electric street traction, which I consider an anachronism and should be swept away, root and branch, from our ground-level thoroughfares. The combination of load factors, however, assumes quite another aspect from the broader point of view of increasing the general consumption. Each small economy in production, followed naturally by lower charges, leads to an increased demand for heating, lighting, and power, and tends to that broadening of the basis of supply which will ultimately produce a load factor higher than that which exists at present, even in our imagination. If with the present restricted use of electric lighting the general load factor be not sensibly lowered, there can be no doubt that with the enormously increased use which will follow further improvements in the transformation of electrical energy into light, the load factor may even be improved by the combination of lighting with the other classes of supply. The author is therefore to be commended in his advocacy of combined power stations and distribution systems for all classes of supply.

Mr. Simon. Mr. S. A. Simon: This address should be of interest to everybody connected with electrical engineering because it affects the spread of the use of electricity. Manufacturers and contractors are as much interested in that as the central-station engineers themselves; in fact, they all have to work hand in hand. It is no good having large stations unless there is a load for them, and it is impossible to obtain a load for the stations unless we are in a position to make our prices such that consumers will be induced to use electricity rather than other forms of power, lighting, and heating. Dr. Klingenberg shows fairly conclusively that even under such bad conditions as those in London it would pay to erect large central stations and to scrap the existing plant; and that after allowing for capital charges there would still be a considerable surplus, which would no doubt be utilized in reducing the price of electricity, and thus enabling a larger number of consumers to utilize this form of energy. I do not quite agree with Mr. Newington that London is not a good example to take. On the contrary, I think some of the conditions in London are not very different from those in other areas with equal population. What applies to a large city would also apply to a large area; for instance, in Scotland one might include in one area Glasgow, Edinburgh, and the surrounding towns, and consider whether the supply of electricity from one, two, or three large stations linked together would not be better than the supply as it is with each municipality, each small town, and each outlying district having its own system. When we consider the whole of the south of Scotland, we are greatly handicapped by the multiplicity of systems and voltages. In Glasgow the city is supplied with continuous current at 250 and 500 volts and three-phase current at 25 cycles; the Clyde Valley Electrical Power Company supply three-phase current at 25 cycles, but at a different voltage from the city supply, whilst the outlying towns have continuous-current supplies with voltages varying from 200 to 250. Further east there are two-phase and three-phase supplies at 50 cycles, and Edinburgh has a continuous-current supply at 230 volts. This multiplicity of systems makes it impossible for manufacturers and contractors to keep the necessary stocks, and it adds to the difficulties of manufacture. This must tell on the prices which the public have to pay for their apparatus, and by increasing the cost and time required for supplying electrical plant must militate against its more general adoption. The question of big stations for the supply of large cities and districts is one of great importance. Any proposal that would conduce to greater uniformity and a cheapening of the cost deserves serious and immediate consideration.

Mr. Seddon. Mr. E. Seddon: A consumer is frequently offered a supply of energy at a certain price and at a certain load factor, although the latter appears to form an entirely wrong basis for fixing a price, inasmuch as it depends principally on the extent to which the prospective consumer is able to improve the load factor at the generating station. The consumer will sometimes offer a 60 per cent load factor when with a different time of peak a load

factor of 30 per cent would be more profitable to the undertaking, *i.e.* if the peak of the prospective load coincides with the station peak a higher price per unit would be chargeable with the same load factor than would be the case if the consumer's peak did not coincide with the maximum load at the station. The better practice would be to hand a copy of the station load curve to the consumer with the statement that the lowest possible price would be quoted if he could provide a load which would allow the valleys in the curve to be filled up. The question of scrapping plant is a very important consideration when a high price per kilowatt has been paid and when the period over which the loan is spread has still a considerable time to run. In the present state of the law, plant which has not been paid for cannot be scrapped, for otherwise the balance-sheet of the undertaking would show liabilities against which there were no assets. There is, of course, no reason why modern plant should not be added to an old station leaving the old plant standing until the undertaking can afford to buy it out.

Mr. G. S. HELME: There is a point on page 129 which I think has not been sufficiently emphasized. The author states that the nature of the load in London should be altered; the same remark might be applied to other large towns. In my opinion this alteration should be on the lines of encouraging the consumers to adopt electric heating and cooking. Central-station engineers, though doing more than they did in the past to cater for this kind of load, have still plenty of scope for improvement, in that far too much is left to the manufacturer in the way of reducing the initial cost of apparatus in order to compete with gas and coal. A feeling has been prevalent that central-station engineers have been far too anxious in the past to secure large works as consumers, and this policy often results in prices being cut to such an extent that it is debatable whether current can be generated at the price charged for it.

Mr. J. A. ROBERTSON: The question which interests us most is the London problem. I suppose that if we had to start afresh nobody would dream of putting down 64 small stations to supply the London area. It is remarkable, however, that in looking into the tables of comparative costs, how well the London stations come out when we take into consideration the cost of coal freight and the absence of proper condensing facilities. I make it out that while the total works costs for London amount to 1·02d., for Berlin after deducting the amount of municipal participation they are 0·612d., and for Chicago 0·54d. Part of the higher cost in London is accounted for by rent, rates, and taxes, over which the undertakings have no control, so that the difference is not so great as it appears at first sight. I agree with Mr. Newington, however, that London should not be taken as an example of the best we can do in this country. Many of the London undertakings represent pioneer work and are burdened with obsolete plant, and handicapped by conditions which do not exist either in Berlin or Chicago. One reason why these stations have not been scrapped in favour of several large central stations is the purchase conditions of the 1888 Act and the fact that the companies owning these undertakings can have very little idea of the terms on which their undertakings may be purchased when the local authorities come to exercise their statutory powers. If Dr. Klingenberg had taken one or two large provincial stations such as those at Manchester or Birmingham, he would find that the relative costs of generation and the selling price compare very favourably indeed with Berlin or Chicago. The figures given for Chicago show the immense importance of a traction load combined with a power and lighting load, and there is no doubt, I think, that the proper thing to do is to combine all the classes of supply in one station so as to obtain the highest possible diversity factor. Dr. Klingenberg compares the relative costs of a station near the centre of supply with a distant station. The idea of placing large generating stations in the coalfields appears a very attractive proposition. It must be remembered, however, that the modern power station depends on steam turbines for cheap generation, and to work turbines efficiently an ample supply of condensing water is necessary. This supply will not always be available in the coalfield districts, so that the sites of the large power stations of the future must be a compromise; they must be placed where coal freight is not excessive and where water is abundant.

Mr. Robertson.

I was surprised to learn that the Berlin municipality extracted so large a sum as 10 per cent of the gross income of the supply company as the price of the concession, in addition to participating in the profits over a certain sum. We hear a good deal about the vicious practice of taking profits from supply undertakings in this country in aid of the rates, but I do not think that any municipality in this country would dream of taking 10 per cent of the whole income in aid of the city treasury. This diversion of revenue from the electricity undertaking, which amounts to more than the coal bill in the case of the Berlin undertaking, is really a tax on consumers of electrical energy, and I do not think it is fair or reasonable for the electric supply industry to be burdened with such a charge. In considering the London problem we have to accept the fact that these 64 undertakings are established, and while it is impossible to scrap them at once, much can be done by combining the larger undertakings and gradually changing the smaller stations into sub-stations. The whole question is at present being considered by the County Council with the aid of expert advice, and it is probable that we shall have a concrete proposal to discuss at an early date. It will be found in many cases that existing stations can be extended economically and ultimately linked up with one or two large power stations which will represent the most modern ideas in design and equipment. Any conclusions based on the number of units sold per head of population may be somewhat misleading. We have heard about the extensive use of electricity in Chicago, but if the amount of the traction load in Chicago is deducted and the remainder is divided by the population it will be found that the number of units sold per head for power and lighting is 110. In London the corresponding figure is 70 units, but in Manchester it is 99, while in Greenock the figure is 136 units per head, and in several English towns it is well over 100. I mention these figures to show that the position in this country is not so bad by comparison as it appears on the surface.

Mr. W. W. LACKIE: I agree with what Mr. Newington said: the London undertakings commenced their supply in 1882, and Berlin and Chicago in 1888 and 1907; so that the two cases are not really comparable. The mains in

Mr. Lackie.

Mr. Lackie. London, which could still be used, represent £13,000,000, whilst the capital expended in London on electrical undertakings is £27,000,000. I believe the load factors mentioned will be obtained when there is a universal supply of electrical energy. Only a few years ago a Glasgow firm generated as many units as the Corporation Electricity department did, but at a 60 per cent load factor. I believe that the tramway load in Glasgow has only a 36 per cent load factor, but in Chicago the combined load factor is 41 per cent. Mr. Mavor raises the question of spare plant. I think the author merely mentioned that there should be one unit spare, *i.e.* with four 10,000-kw. sets there should at least be one spare. Dr. Klingenberg refers on page 126 to the cost, and gives a formula for it, but I should not like to go to a consumer and tell him that that is how the costs are made up. Like Mr. Seddon, I should prefer to show the load curve and tell the consumer that I want him to improve that curve, and a price can then be arranged. Mr. Simon suggested large stations of uniform voltage. When the pressure was raised in Glasgow to 250 volts we were told that the price of lamps would be doubled if everybody adopted a uniform pressure. Mr. Seddon referred to load factor: we have a case where there are two mills, one running all day and the other all night; the load factor of each mill is 30 per cent, but we shall have a 60 per cent load factor on the station. Mr. Helme says we are not catering for new sources of supply. I think we are, and I would refer him to the recent Electrical Exhibition in Glasgow, which was most successful. The erection of a station near a coal-mine raises a very debatable point; for if a station is placed near a coal-mine it is tied to that one pit, and if a coal strike takes place at that pit where can coal be obtained? It is better to be so situated that coal can be obtained from any pit. In Chicago, three independent stations are being built on one site, and it is believed that a 240,000-kw. station is the largest that should be built. I have seen the site and the plans for these three stations, and I notice that it is considered the correct policy to build the stations inside the city and bring the coal in. I do not see how the nature of the consumption in London is to be altered. We have got to take the present conditions.

There is one other point. Nowhere throughout the paper has Dr. Klingenberg referred to the effect of the diversity factor, which is a most important factor in the sale of electrical energy. The number of units sold per head of population in Greenock, which holds the record in this country, is 135, double what it is in Glasgow. It shows the nature of the load, which is largely power. A sum of £500,000 was spent in Chicago last year in installing battery sub-stations. It is believed there that everything possible must be done to ensure reliability of supply, and the lighting of the whole of the centre of the city can be supplied from storage batteries if necessary. This means an increase of £2 per kilowatt in the cost of the plant. It is most difficult to make comparisons between one town and another, and while Dr. Klingenberg's address is of great interest and value it is not one which can be readily discussed as a technical subject.

Dr. Klingenberg. Dr. G. KLINGENBERG (*in reply, communicated*): Mr. Newington's remarks as to the difficulty of overcoming the large capital expenditure on the existing stations and the repayment of this debt might be justified if I had assumed that all the existing stations were to be replaced at one time. However, from the information which I possessed I felt convinced of the practical impossibility of such a proceeding, and I therefore confined myself to a programme whereby the reconstruction could be carried out step by step without interfering with the liabilities due to the existing capital. The surplus arrived at in Table VI shows that the first step in the programme which I adopted promises to be in the right direction, because this surplus was obtained after I had allowed 8 and 10 per cent on the new, and 8 per cent on the present capital of the 25 old stations (see items 14 and 16, Table VI). The last percentage for paying off is even higher than the average total percentage (7·85 per cent according to item 30, Table III) earned under operation during the year 1910–11.

Criticism has been raised with regard to the load curves for power and traction shown in Fig. 1, which were based on a load factor of 50 per cent. Apparently it is overlooked that these diagrams refer only to large power stations, and that the load factors therefore represent values obtainable under the best conditions, *i.e.* with the highest diversity effect for each individual class of consumption given in Fig. 1. In regard to power especially it must further be taken into account that in large cities the load on Sundays falls almost to zero, so that the yearly load factor (Fig. 1 refers to daily load diagrams, excluding Sundays) for power will be smaller approximately in the ratio of 6 to 7. A similar, though not so great a reduction, will apply to the load factor for light and traction if taken over the year, depending on the special living conditions in the towns on Sundays.

It should further be noted that the load factors in Fig. 1, contrary to English custom (see the statistics published by the *Electrical Times*), are based on the number of kilowatt-hours generated; in order, therefore, to bring these values into line with the load factors given in the *Electrical Times*, they have to be multiplied by the efficiency of the transmission. Taking this into account, it will be found that the actual load factors (item 20, Table III) compare very well with the values taken from Fig. 4 (which is based on Fig. 1), and seem therefore to confirm the correctness of the load curves in Fig. 1.

It has been pointed out that I have made no reference to the selling price of the current. This remark is only correct in so far as I have not discussed the individual selling costs for the different classes of consumers, which I considered to be outside the scope of my address: all that appeared to me to be important in connection with the subject was the average selling price of electrical energy in the case of large companies. This point has been fully dealt with, both as regards the actual prices obtained (see Fig. 5 and item 31, Table III) and the desirable or "normal" prices as I have called them. From my explanation of "normal selling price," it will be seen that I do not consider the results of the various towns to be directly comparable with one another, but that I attribute to each town a scale of "normal selling prices" representing, generally speaking, the lowest prices at which a prosperous development can still be expected under the prevailing conditions. These curves and formulæ therefore offer the safest guide in predetermining the price for current as closely as possible, and beyond this the method used opens out a new prospect with regard to the question

of tariffs. In this connection I come to a point raised by Mr. E. Seddon, viz. that instead of offering a customer a price based on his load factor, the price should be fixed according to the improvement of the load factor at the generating station. This I consider to be fully correct, except that as a result of my researches in this respect I have to go a step further than Mr. Seddon, by maintaining that the selling price to each customer should be based upon his utilization of the whole undertaking, *i.e.* on his improvement of the utility factor of the entire system, instead of on the load factor of the central station only. It is of course practically impossible to determine this effect for each individual customer. My address, however, contained a practical proposal towards the above ideal way of fixing the tariff. I showed that in large cities the load curves of special classes of consumers could be considered as constant, no matter what the load factor of a single consumer in such a class might be ; or, to put it differently, that in large cities for certain classes of load the diversity had reached its maximum. Once this has been admitted, all that is necessary for the ideal tariff is to find the diversity amongst the classes of demand for any combination. This I have done in Fig. 4 (see also page 148 in my reply to the London discussion) for the three classes—light, power, and traction. My address therefore involves the conclusion that a tariff based only on the maximum of the individual consumers is wrong for large cities.

By "Nature of consumption for London" (page 129), to which Mr. Lackie refers, is meant the combination of power, light, and traction, which can be altered, for instance in London, if more traction load is included in the general supply.

Several engineers have remarked that the data I have given for practical examples were not well chosen. I admit this to the extent that it would have been to some extent advantageous if I had discussed the latest data for 1912–13, but unfortunately I was not able to secure the same complete, authenticated information simultaneously in all three cases for years later than those which I have taken. In other respects I must uphold what I said in the address, that I consider the plants of Berlin, Chicago, and London as good examples as I could find with regard to the subject of my address, and I believe that a comparison of their historical development with the capital expended on and the working results obtained from them will confirm this contention.

In reply to the remark that I ought rather to have taken another English city instead of London in order to show better working results, I can only say that my address is misunderstood, since it was not intended to compare towns on the basis of maximum records for working costs. If this had been the case very probably none of the examples that I have taken would have appeared in the address ; and I can only say that if any qualifying conclusions are drawn from my address regarding the engineering of the average London supply (see especially Fig. 5), these could not be otherwise than highly complimentary to the London engineers, who, notwithstanding the extremely unfavourable conditions, have been able to manage the supply in such a way that they lag neither in regard to reliability of supply nor in price of current behind the works of similar large cities which were placed in a much better initial position.

I regret that owing to an oversight I omitted to mention in the copy of my address printed in the *Journal* the cooperation of my assistant, Mr. R. Tröger, which I acknowledged when reading my address before the Institution I take this opportunity of expressing my best thanks to Mr. Tröger for the valuable assistance which he has rendered me.

NOTES ON INTERNATIONAL STANDARDIZATION OF ELECTRICAL MACHINERY.

By A. R. Everest, Member.

(Introductory notes to a discussion before the Birmingham Local Section, *10th December,* 1913.)

In all engineering work, in order to produce satisfactory results, it is necessary that there should be a knowledge of the behaviour of materials under different degrees of duty, and that the parts should be so proportioned that the working duty may bear a known relation to the safe limits. In other words there must be a known "safety factor." In mechanical engineering many decades of practical experience, together with persistent research work, have placed at the engineer's disposal the information needed to determine on the one hand what safety factor is proper for the duty in question, and on the other hand what proportions are needed to give the required safety factor.

In the design of electrical machinery similar information is necessary; but due to the rapid development of this branch of engineering, such information has not been in the same way available.

One of the principal tasks assumed by the International Electrotechnical Commission has been to study this subject through the various National Committees in order that all available experience may be brought to bear in establishing the necessary reference data. The information thus collected and discussed internationally at the meetings of the Commission in Paris, Zurich, and finally Berlin, has now been reduced to a form in which it becomes available for practical purposes, and various countries are now engaged in remodelling their National Standardization Rules in accordance with the new I.E.C. standards so far as these have been established.

In order properly to discuss the work of the International Electrotechnical Commission it is necessary to distinguish clearly between an "international standard of quality" and an "international rating" for machines.

The rating of a machine is the output for which it is sold and which is marked on its name-plate (rating plate). This output is the "rated output" of the machine.

(*a*) *I.E.C. Standard of Quality.*—If the rated output of a machine is such that when working under the particular cooling conditions for which it is designed the machine keeps within the I.E.C. limits of temperature, this machine, for its particular application, conforms to the I.E.C. standard of quality. This standard is particularly valuable for important individual and special applications. Various machines in this class from different sources would still not be directly comparable, since they would not have an equal temperature rise if primarily intended for different conditions.

(*b*) *I.E.C. Rating.*—If the rated output of the machine is such that when working under the I.E.C. standard conditions of cooling the machine keeps within I.E.C. limits of temperature the rating of this machine is I.E.C. rating. Thus the I.E.C. rating establishes temperature rise as well as maximum temperature. All machines with I.E.C. rating would be directly comparable amongst themselves since they would all have the same temperature rise at their rated output.

The Rules adopted at the recent I.E.C. meeting in Berlin establish the I.E.C. standard of quality (as regards temperature) for electrical machinery. Agreement was not reached upon the further question of I.E.C. rating, due to differences of opinion regarding the value for the cooling-air temperature. Before referring further to this feature it may be well briefly to review that part of the work which has been completed by the I.E.C.

These Rules are the outcome of deliberations by the various National Committees and at the meetings of the Special Committee on Rating held in Paris and Zurich, and in Berlin prior to the Plenary Meeting.

The Rules so far adopted are based on considerations of the highest safe temperatures for various insulating materials, the joint effect of time and temperature, also the probable difference between observable temperature and maximum internal temperature. From these considerations an international agreement was reached regarding the permissible limits of temperature for various insulating materials employed in modern electrical machinery. In connection with these permissible temperature limits, rules are provided regarding the proper determination of the temperature of the cooling air, a knowledge of which is necessary to ascertain the temperature rise which must not be exceeded at the rated load of the machine.

Finally, rules are provided dealing with the differences which may exist between the temperature rise on test and under service conditions due to variations in the cooling temperature and the barometric conditions. Thus the I.E.C. standard of quality has now been established as regards temperature, and therefore life, for any machine working under the conditions for which it is sold.

Method by which Temperature is to be observed.

While the hottest internal temperature at any point determines the life of the insulation affected, the I.E.C. does not consider it feasible to make this the subject of ordinary commercial investigation. Information obtained from laboratory investigations with exploring coils and thermo-couples built into specially prepared machines appears to justify the conclusion that for modern machines wound for not more than 4,000 volts, or for transformer coils for not more than 10,000 volts, the hottest internal spot will not exceed the temperature observed by ordinary methods by more than 10 degrees Centigrade. Accordingly the limiting observable temperatures permitted, which are shown in the Table below, apply to measurements by the rise of resistance of the winding (wherever practicable), together with the use of thermometers, the highest reading found being always con-

sidered. Electrical thermometers and thermo-couples applied to any accessible part of a completed machine are classed with thermometers.

The Question of Overloads.

A great deal of confusion exists between different countries at present concerning the relation between the so-called "full load" rating of a machine and the highest load it is actually expected to carry. Further, the various overloads are rated for different lengths of time, and in some cases are not allowed at all when the machine has been heated up by its ordinary "full load."

The I.E.C. has decided that any machine intended for continuous service should be ordered, designed, and rated for the highest load it is expected to carry, and that it should be capable of carrying this rated load continuously without exceeding the temperature limits of the Table. No overloads are permissible beyond this rated load.

In the case of a machine subject to peak loads in excess of the ordinary load, if the peak endures for more than a short time it must be included in the rating. But if the peak load is to be endured for brief periods only, the rating must be sufficiently above the ordinary load to give a continuous thermal capacity equivalent to that required on the brief peak loads without exceeding the permissible temperature limits.

Intermittent Service.

A machine for intermittent service may for the purpose of test have either a continuous rating which is thermally equivalent, or a "short time" rating which when starting cold and running at a rated load for a specified time shall not at the end of that time attain temperatures in excess of those shown in the Table.

Permissible Limits of Observable Temperature.

Upon these considerations the I.E.C. decided to standardize limiting values for temperature which should apply to "observable temperatures" measured by the means and methods specified, and which should be set with due allowance for such excess internal temperatures above those "observable" as would be associated with the approved methods of test. The temperatures were to be such as might be endured continuously without prejudice to a reasonably long life, but there were to be limits which must not be exceeded. Accordingly values have been standardized as shown in the following Table :—

Table.

Limits of Observable Temperature adopted by the International Electrotechnical Commission, September, 1913.

	C.
Non-impregnated cotton ...	80°
Impregnated cotton or paper (general)...	90°
,, single layer field coils stationary or moving...	95°
,, stationary coils solidly impregnated throughout	95°
,, rotor and stator windings having the slot portion solidly impregnated or moulded	95°
Enamelled wire (without cotton)...	105°
Mica, micanite, asbestos (general)	115°
,, single layer field coils stationary or moving...	120°
,, stationary coils solidly impregnated or moulded	120°
Windings permanently short-circuited—	
Insulated ...	100°
Non-insulated ...	110°
Commutators, slip-rings ...	90°
Bearings ...	80°

Note: When the insulation is composed of several different insulating materials the lowest of the temperatures corresponding to the various insulations employed must be taken as the temperature limit. The insulation even when forming a support is always considered as part of the winding. (Material employed in small quantity in the construction and not relied upon continuously as a support for the insulating material is not regarded as part of the insulation under this rule.)

Statement of Cooling-air Temperature.

Permissible limits of temperature are useless to the designer except in conjunction with information regarding the cooling temperature, since the difference between these two values is the "temperature rise" which the machine may create when carrying its rated load. Hitherto in the I.E.C. proceedings, as well as in the various National Rules, the value mentioned as cooling-air temperature has been the "ordinary" or average value. Obviously such value cannot be used directly in connection with a table of limiting temperatures "which must never be exceeded."

The corresponding value of the air temperature employed must be the highest which is likely to occur. The British and United States Committees agreed in recommending that in future 40° C. should be taken as the reference air temperature, instead of 25° C. as hitherto indicated in the National Rules. (Unfortunately some confusion arose because the reason for this sudden increase from 25° C. to 40° C. on the part of the British and United States Committees was not explicitly given.)

The I.E.C. Rules now require that the maximum and not the average temperature of the cooling air shall be stated, but agreement was not reached regarding an International Standard reference air temperature. This will be referred to again under "I.E.C. Rating."

Correction for Room Temperature during Test.

Extended investigations made by the United States National Committee show that the variation in temperature rise with a given load when tested with cooling air at different temperatures is a small and uncertain quantity, sometimes positive, sometimes negative, according to the characteristics of the particular machine. The I.E.C. decided that no correction shall be made in practice for such difference between the conditions of test and of final service.

Corrections for Difference of Altitude.

No correction is to be made for variation in the cooling properties of the air at a given temperature at altitudes

not exceeding 1,000 metres. For higher altitudes it is recognized that a correction is necessary, but the I.E.C. is not yet in a position to furnish an official correction factor.

"I.E.C. Rating" for Machines.

Although the I.E.C. states that "wherever possible the temperature of the cooling air should be stated and the machine constructed for this cooling condition," it is also proposed to establish a value which shall be taken as the maximum temperature of the cooling air when no specific information is available. Probably more than 90 per cent of all the machines sold come under this class, and the establishment of an international reference for air temperature in connection with the Table of limiting temperatures already provided would at once fix the temperature rise permissible at the rated load, and in connection with the rulings given regarding overload would completely establish the capacity of any machine sold with "I.E.C. rating."

With such uniform rating adopted, a buyer of standard machines could compare, without misunderstanding or possibility of mistake, tenders received from various makers even from different countries. He would know that all the machines offered would carry their rated loads continuously with the same temperature rise (and also with uniformity in other characteristics such as commutation, as far as these might be defined by the I.E.C. Rules).

It is evidently desirable that the I.E.C. rating shall also be the domestic standard rating of the same machines in the countries in which they are produced. The reference air temperature must then be set at such a value as shall not be exceeded by the hottest conditions likely to occur in service at any time of the year in any temperate climate.

At Berlin a majority of the delegates, including those from Great Britain and the United States, desired to fix this reference temperature at 40° C., but a minority desired 35° C.

Examination of the meteorological records for various temperate countries, including Great Britain, Germany, and the temperate part of the United States, shows that 35° C. is not sufficiently high to cover even the highest outdoor shade-temperatures which are occasionally recorded, so that with a temperature rise based on the 35° assumption the limiting temperatures of the I.E.C. Table would certainly be exceeded at times. But such is contrary to the express conditions under which the limiting temperatures were adopted by the I.E.C.

In order to justify a *nominal* "maximum" temperature for cooling air which would exclude the highest peaks occasionally occurring, it would be necessary to reduce all the values shown in the Table of permissible limiting temperatures by a margin sufficient to allow for such occasional peaks. This proposition was suggested at Berlin but was not accepted by those desiring the lower reference temperature. Finally, this entire question was referred back to the various National Committees, and it is to be hoped that an early settlement will be reached, as upon this question hangs in reality the whole problem of international standardization in the rating of electrical machinery.

Discussion.

Mr Peck. Mr. J. S. Peck: Probably there is no one who will question the desirability of having international standards for the rating of electrical machinery. The standard rules should prove of special benefit to British manufacturers on account of the fact that the German "Normalien" are the standards most generally recognized in the majority of countries to which we export; and since British standards have in general been higher than the German, the British manufacturer has been at a disadvantage when tendering his standard machines against those of Continental manufacture. Continental engineers were probably the first to recognize the desirability of permitting a much higher temperature rise on machines insulated with fireproof materials than on those insulated with treated or untreated fibrous materials. American engineers are now advocating very high temperatures on machines such as turbo-generators where fireproof material is used, and apparently the results of machines in commercial operation justify this practice. It would appear that at last the various nations have practically agreed on the absolute temperatures at which different classes of insulating material can be operated. One point in the proposed rules seems likely to cause considerable misunderstanding. This is the substitution of maximum rating for normal rating with overload. The trouble is, however, chiefly a mental one, for the same factors as formerly will have to be taken into consideration, and the customer must place before the manufacturer the conditions under which the apparatus will be required to operate in the same way that he does at present. I think special attention should be drawn to the note at the bottom of the table on page 245 giving the limits of observable temperature. Fireproof material such as mica cannot be applied for armature wrappings except with a backing of thin cloth or paper; yet this paper or cloth may be completely carbonized and disintegrated without affecting the insulation strength of the machine; and in such cases it comes under the class in which the highest temperatures are allowed.

Mr. Larke. Mr. W. J. Larke: It is of the utmost importance in the interests of the development of the electrical industry throughout the world, as well as of foreign business in the countries which do not produce their own electrical machinery and apparatus, that an international agreement should be arrived at in connection with standardization. As Mr. Peck has stated, in the latter countries we have for some considerable time been at a serious disadvantage compared with our German competitors, due to our adoption of a more conservative basis of rating. But the work of the Commission will prove abortive unless each country represented on it takes the requisite steps to ensure that the recognized authorities controlling the standards of the industry in that country co-operate with the Commission, by changing where necessary the recognized standards of the country to those formulated by the Commission to which their representatives have subscribed. For the United Kingdom this authority will presumably be the Engineering Standards Committee.

It is interesting to note that in America the Institute of Electrical Engineers has already drafted a comprehensive series of rules in which has been incorporated the standards formulated by the Commission so far as these have been established by international agreement. It is unfortunate that the Commission were unable to reach an agreement on what has been termed the "ambient temperature," or temperature of the surrounding air, and Mr. Everest rightly points out that on this question rests the whole problem of international standardization in the rating of electrical machinery. There is no doubt that the attitude of the British and American delegates is correct in supporting such a limit for the ambient temperature as will ensure, under the conditions of climate considered, that the maximum limits of temperature mentioned in the table given by Mr. Everest—the figures in which have been adopted by the Commission—are never exceeded during any period of the working time; and this is the only logical attitude in view of the fact that the limits mentioned are the maxima. As for temperate climates, the limits of ambient temperature should be equal to the maximum recorded during any season of the year, which is given as 40° C. It is to be hoped that at the next meeting of the Commission this limit will be agreed upon, the arguments in its favour being irrefutable. In connection with the table of limits of maximum temperature for various materials, recognition should be given to the extremely valuable pioneer work carried out by a Committee under the chairmanship of Dr. Glazebrook in 1905. It was undoubtedly those important and comprehensive investigations which rendered the compilation of the table now under consideration possible. Reference has been made to what in America is described as the "hot-spot" of machines and apparatus, but it seems both unnecessary and undesirable to take this into consideration in ordinary commercial practice, particularly as the Commission has definitely stated that the difference in temperature between the "hot-spot" and the temperature of those parts of machines or apparatus which are readily observable, has already been taken into account in determining the limits of temperature which the Commission has adopted for the various materials. This difference can obviously only be determined by investigation under research conditions, and it is far preferable that the standards which are to govern the commercial development of the industry should be formulated in such a manner that the tests for determining compliance with such standards may be readily applied under ordinary manufacturing conditions.

With regard to the question of rating, which, as has been already stated, is dependent on the ambient temperature, if 40° C. is adopted for temperate zones, there will arise the difficulty of the rating of machines exported to tropical zones. It must be borne in mind that standards of the character it is proposed to set up apply equally to small machines as to large machines, and whereas large machines are almost invariably specially designed and built for the conditions under which they are required to work, and therefore questions of the ambient temperature or any other local conditions affecting the design can be readily allowed for, in the case of small machines manufactured in quantities this is not possible without following the same procedure as that applied in the case of large machines. Thus a difficulty arises as to the rating of these small machines which it is desired to deliver from stock for shipment to tropical zones. It seems evident that in every case the ambient temperature of the locality in which the machines are to be used must be taken into consideration, and the machines re-rated accordingly by the manufacturer supplying them, as obviously the user is quite unable to assume the responsibility of re-rating these machines to suit his local conditions if they were supplied on a basis of rating determined by the ambient temperature for temperate zones. With regard to the suggestion that motors should be rated in kilowatts instead of horse-power, this is an innovation for which there seems no reasonable grounds, and one that will be fraught with the greatest possible difficulty and inconvenience. From what may be claimed a considerable experience and acquaintance with users of electrical machinery, it may be definitely stated that the difficulties of introducing electric driving, particularly to small users, will be considerably enhanced by following this procedure. All prospective users of electric power think in horse-power, and any prime-mover which it is proposed to supersede by an electric motor is invariably rated in horse-power unless it is a manually-operated device. To introduce needlessly a new unit which would require explanation and discussion with the prospective user, and without obtaining any but an academic advantage, would introduce a modification which if in itself of minor importance (since two sets of ratings in catalogues, etc., could be printed) is at the same time detrimental to the best interests of the industry.

Mr. Larke

Mr. C. LE MAISTRE: The electrical industry is to be congratulated upon the public-spirited and cordial way in which the manufacturers are co-operating in the establishment of satisfactory standards for this country. The close co-operation recently established between the American Standards Committee and the British Engineering Standards Committee is certain to be of mutual advantage to both countries and will ensure the adoption, by English-speaking people, of standards of the highest quality. The general public now have confidence in the freedom from breakdown of English electrical machinery, and whatever standards are adopted in this country must be of such a nature as not in any way to encroach on this confidence. As regards the international aspect of the question, I feel quite confident of the ultimate success of this work, for our continental friends have, in just the same manner as the English and American engineers, placed their very best men at the disposal of the Commission for the working out of these problems, and Mr. Everest will bear me out when I say that the Delegates to the Special Committee, both at Zurich and at Berlin, were all actuated by the highest motives. Although it is only a small part of the work to be accomplished, the recommendations which the Commission has already made in regard to the rating of machinery will appeal to both maker and user alike as being of real utility. Again, the standards adopted by the Commission must be of a really international character if they are to command the respect of the world; and the interests of those countries which are either hotter or colder than temperate climates must carefully be borne in mind. It is true, of course, that temperate climates contain the very large majority of users of electrical machinery. As General Secretary of the Commission, even were I competent to do so, I am debarred from entering into any detailed criticism

Mr. Le Maistre.

Mr. Le Maistre

of Mr. Everest's notes, but I may mention that the Central Office of the Commission in London will do everything in its power to help forward international agreement on this important subject. To be able equitably to compare different tenders must be of such material advantage to the progress of international trade in electrical machinery —and the difficulties of arriving at a satisfactory basis of comparison are by no means insurmountable with so much good-will at the disposal of the Commission—that it is well worth striving for.

Dr. Kapp.

Dr. G. KAPP: The decision of the International Electrotechnical Commission not to establish any rules for the correction to be made for ambient temperature or altitude is justified by the contradictory experiences brought forward by several delegates. As the influence of the density of the cooling medium is exceedingly complex, this may account for the discrepancies between the results obtained by different observers. On a superficial consideration of the problem it would naturally be supposed that the cooling effect of the air would be reduced if its density were lowered, either by reason of a higher initial temperature or a higher altitude. It should be remembered, however, that it is not the volume but the weight of air and the velocity at which it passes along the surfaces that determines the number of calories which it can carry away. As it is quite conceivable that owing to the special configuration of the body or the supply of a definite power in working a ventilator there would be no great reduction in weight of the air passing the body in unit time whilst the velocity is increased, no material difference in the temperature rise would be observed whatever the density of the air (within reasonable limits). As regards the question of a standard ambient temperature, I would point out that the adoption of 40° C., as advocated by the British and American members of the Commission, is not unreasonable, when the necessity of providing a certain factor of safety is considered. The yield point in the stress of a bar of steel can be found with a fair degree of accuracy, but the thermal yield point of any particular type of insulating material is not so accurately known. That such a point exists has been shown by Mr. Rayner, and later by Dr. Steinmetz and the brilliant group of American engineers working on this subject; and although it may not be known to 1 degree with absolute certainty, all experts agree that a decrease or increase of 5 degrees makes all the difference between a long and a short life of the insulation. The Commission has agreed on certain upper limits of "observable" temperature; these values are probably not very far from the yield points and for this reason they must not be overstepped. It is therefore a wise precaution to agree on an ambient temperature sufficiently high to ensure that these maximum temperatures shall not be exceeded even on a hot summer's day. The cost of a machine is only slightly increased by adopting the ambient temperature of 40° C. as a starting-point to arrive at the permissible rise, whilst the extra security against breakdown and the consequent possibility of reducing the amount of spare plant are certainly in the interest of the user. Nowadays, when electricity has become so important a factor in all industries, electrical engineers must not run any avoidable risk, and even if the provision of a generous factor of safety should increase the cost of a machine by a few per cent, it is eventually in the interest of the user to pay a little more for a reliable article than a little less for a cheaper and unreliable article. This is the policy followed by the best English and American practice, and in the interests of electrical engineering we can wish for nothing better than that it should become the policy of electrical engineers of all countries.

Dr. Kahn.

Dr. M. KAHN: As Mr. Everest has pointed out, two questions have arisen in connection with the standardization of temperatures of electrical machinery:—(1) "Maximum temperature limits" (these have been agreed upon by the International Standardization Committee and need not be discussed); (2) "temperature rise" (no agreement has been reached upon this question). Some points which have to be considered in settling the temperature rise that can be allowed are as follows:—The electric motor is now practically without competition for the ordinary commercial drive, so that the question of rating can be settled by representatives of the electrical industry without regard to competing methods. There are of course a few cases like the driving of cotton mills or large rolling mills, or heavy traction, where the electric motor is still in competition with other means of driving, but such cases may be neglected, as the considerations which will finally determine the issues are other than those under discussion to-night. There cannot be any doubt that a conservative rating is to the best advantage of all concerned. Above all, the user of electrical machinery requires reliability, and the manufacturer of electrical machinery has the greatest interest in supplying a thoroughly reliable article. If a conservative rating is universally adopted, the only consequence will be that the price of electrical machinery will be kept at a certain standard; this can only be to the advantage of everybody concerned, including the buyer, as the latter receives a satisfactory article which will ultimately cost him in upkeep and repairs less than a machine that is rated too high.

There is no doubt that machines sometimes have to run in rooms where the temperature of the surrounding atmosphere is 40° C. This condition of course does not often prevail. Machines will in the majority of cases run where the temperature is about 25° C., and the difference of 15° C. can be regarded as a factor of safety. Factors of safety are always adopted in engineering, and I do not see any reason why a factor of safety should not also be used in connection with rating. The maximum load that a generator has to carry is usually known, namely, the maximum load the driving prime-mover can give; in the case of motors, however, the maximum load more often than not is unknown both to the user of the motor and to the manufacturer. Moreover, motors are often overloaded—for instance, by adding new plant to that already driven by the motor, or, even without any such alteration, due to increased friction in the bearings of the driven machinery and the line shafting. It may of course be said that this should be allowed for when ordering a machine; but I am quite certain that it would be impossible to persuade a customer who has been accustomed to buy a 20-h.p. motor and obtain a certain power from it whilst also having something in hand for contingencies, that in future he will have to specify a maximum load with a certain margin above the normal load. In other words, if he wants a 20-h.p. motor he would have to buy a 25-h.p. motor. All this can be obviated if the rating of the motor

is settled in such a way that in case the rating allowed is exceeded by a reasonable limit no harm will be done to the machinery installed. It may of course be said that it is unnecessary to settle temperature rise at all, and that the temperature of the surrounding atmosphere can be stated in every case. This has as a matter of fact been done to a certain extent by the decision temporarily arrived at at the latest meeting of the International Standards Committee, but this solution is most unsatisfactory as it is essential for the manufacturer to standardize.

Mr. C. T. Siebs: I should like to congratulate Dr. Kapp on his lucid explanation of the reason why the temperature rise of electrical machinery is unaffected by the value of the initial air temperature. At the same time I should like to point out that his theory does not make any allowance for the actual increase in the value of the loss in such machines at higher initial air temperatures, owing to the increase in the resistance of the windings. With regard to the method by which temperatures of electrical apparatus are to be measured, I think that it is very much to be desired that some definite rule be fixed, standardizing the exact method of measuring the temperature rise of various parts of such machines. Unless this is done the manufacturer who bases his guarantees on a temperature rise by the "increase in resistance" method will be handicapped in comparison with a manufacturer who bases his guarantees on the temperature rise by thermometer. It is to be hoped that in this standardization the tendency will be towards the use of thermometers rather than of the "increase in resistance" method for determining the temperature rise, as although the measurement of temperature rise can usually be more accurately determined by the resistance method, nevertheless, thermometric readings are invariably preferred by customers, owing to direct readings being obtained without the need of any calculations and also owing to their simplicity. On page 245, under the table giving the limits of observable temperature adopted by the Commission, it will be seen that commutators and slip-rings are bracketed together with a final permissible temperature of 90° C. The mechanical construction of slip-rings usually takes the form of a bronze ring shrunk on to a mica-insulated cast-iron hub. With such construction a very high temperature is possible without any fear of the rings becoming affected, whereas with commutators of the usual construction it is extremely difficult to obtain anything like equal expansion of all parts, with the result that a high temperature rise on the commutators is to be deprecated, as trouble may then be expected with high bars, loosening, etc. It will therefore be interesting to hear Mr. Everest's remarks as to the reasons which made the Commission bracket together such dissimilar parts as commutators and slip-rings under a common heading. The I.E.C. Rules described by Mr. Everest, although taking care of possible damage to electrical machinery due to high temperatures, have not made any attempt to define Rules for the sparking limits of continuous-current machines. With continuous-current machines this is quite as important as the standardization of safe temperature limits, and will now be more necessary than ever if the overloads at present universally given with such machines are excluded. In fact there are many cases where continuous-current machines are called upon to give a very heavy output for such short periods that the temperature rise does not enter into the calculations, the limits being sparkless commutation and mechanical strength. I should like to associate myself with Mr. Larke's remarks as to the inadvisability of rating motors on a kilowatt instead of a brake-horse-power basis. Such a rule would undoubtedly only help to confuse consumers, who very often have a fair idea of the brake-horse-power required but would regard a kilowatt rating as meaningless. Mr. Siebs.

Dr. T. F. Wall: I take it that the most important point under discussion is the temperature which the cooling air is to be assumed to attain in any temperate zone in order that the temperature rise allowed by the Commission may be consistent with the limiting values given in the table. On looking at this table I noticed what appeared to me to be the very high values allowed for the limiting temperatures. So far as I know, one of the most extensive pieces of experimental work carried out in connection with the effect of heat on insulating materials is that described in Mr. Rayner's paper.* In view of the data there given and briefly summarized by Dr. Glazebrook who opened the discussion, I think we may conclude that there is not much margin of safety when the values given in the table are adopted; and it would seem desirable that these values should on no account be exceeded. The severe conditions to which coils are exposed in practice, the alternate heating and cooling, the absorption and drying out of the moisture, which as Mr. Evershed showed takes place even in well-shellaced coils, the leakage currents due to the presence of moisture, and the impurities in the atmosphere, all have a deteriorating influence on the insulation, and it would seem to be imperative that the mechanical strength should not be endangered by the temperature rise. Such considerations would seem to suggest that something of the nature of a factor of safety would be desirable. Certainly the highest temperature likely to be experienced in any temperate climate should be taken in conjunction with the table to fix the temperature rise. That is to say if a temperature of 40° C. is not uncommon, then if the value of 35° C. is taken as fixing the permissible value, the temperatures given in the table will in some cases be exceeded, and the danger zone will then be reached. With regard to the rating of motors in kilowatts instead of horse-power, I might suggest as a compromise that the kilowatt rating be adopted, and in those cases in which a customer is better satisfied to know what the horse-power is, this rating might also be given on the name-plate. Dr. Wall.

Dr. A. H. Railing: It is a great pleasure to me, and it must be a source of great satisfaction to Dr. Kapp and Mr. Everest, who have represented us at the International Conference, to see that the practically unanimous opinion of all those who have taken part in this discussion is for the greater margin of safety, thereby fully supporting the attitude which our delegates have taken. Personally, I entirely agree that it would be wrong from a scientific point of view to reduce the margin of safety, and I agree to the higher temperature rise. As far as I am aware the tests that form the basis of our figures for various insulating materials have been carried out under normal conditions. In practice, however, there must be many factors adversely Dr. Railing.

* *Journal I.E.E.*, vol. 34, p. 613, 1905.

Dr. Railing. influencing the life of insulating material and thus reducing the present factor of safety. To mention one or two points: it seems to me that the life of any insulating material does not depend on the temperature reached at any given time, but also on the maximum temperature differences to which the material is subjected. For instance, a motor standing still at night with the temperature at, say, 20 degrees below zero, and running during the daytime with a temperature rise of, say, 50 degrees C. in an atmosphere at 40° C. will have to undergo a maximum temperature variation of 110 degrees. I suggest that the life of the insulating material undergoing such variations of temperature will very probably be less than if the total temperature variation were smaller, although the maximum temperature reached might be identical in the two cases. I assume further that the tests were carried out in an atmosphere which was either dry or contained a normal degree of humidity. I should be glad to hear whether results are available which show how the rise in temperature is affected by the varying degree of humidity, since my experience seems to show that temperature rises vary by a certain amount with a varying degree of water vapour in the atmosphere. I remember that when I was in charge of a test-room the tests carried out in a damp atmosphere seemed to show a slightly smaller temperature rise than those carried out in dry weather. Now it seems clear to me that just as Dr. Kapp showed us that the cooling effect on a body depends upon the speed with which the cooling medium passes that body, or, in other words, on the number of particles that pass in a given time, it must equally depend on the specific heat conductivity of the cooling material, which of necessity must be different for water vapour and air, never mind to what extent. Apart from this consideration of humidity as affecting the actual cooling process, and therefore the temperature rise which can be prescribed, there is no doubt that the life of the insulating material in climates where frequent evaporation and condensation take place must be affected, and therefore that we should use a certain factor of safety in the case of figures obtained without taking such conditions into consideration. A third point is that in all moving machinery the insulating material is to a certain extent subject to varying stresses, which I suppose have not been taken into consideration in the curves. Dr. Kapp has just shown us that, with the higher temperature rise suggested, we should go dangerously near the knee of the curve. If in addition to this we take into consideration facts like those mentioned above, which must be allowed for in practice, it shows how necessary it is to have the factor of safety for which our delegates have stood out, in the form of a smaller temperature rise.

The above is from the theoretical point of view; but I should like to add that the greater margin is equally desirable from the point of view of the purchaser and the manufacturer. We are expending hundreds of thousands of pounds in power stations all over the world. In any of these systems the cost of the generators is an almost negligible quantity. The difference in cost between a safe machine and one which runs dangerously near the permissible limit may be £100 or £200, that is to say, a fraction of 1 per cent of the capital outlay. For such a small sum is it either common sense or commercially good practice to run the risk of breakdowns, which of course bring discredit to the undertaking? If we take Dr R. into consideration the driven machinery, the cost of the same, and the loss in output if any breakdown occurs, we see that the cost of the motors represents a similar small percentage of the total capital outlay of any manufacturing establishment, and that it also pays there to have reliable motive power. We should not hesitate in the case of any big plant to spend in insurance sums representing more than the difference due to a 10 degrees less rise in temperature. I therefore consider that it is utterly unsound from a technical and a commercial point of view to work, for the sake of a negligible increase in the capital outlay, with factors of safety which undoubtedly are on the low side, and which if adopted would only in the end tend to discredit electricity as a motive power. In conclusion, I may say that we can congratulate our delegates on the way in which they have tackled this problem; that they have our full support in the attitude which they have taken up; and that we are of the firm opinion that after carefully considering these proposals the Commission will finally decide in favour of these points, on which of course the whole working of the rules depends. I am of the opinion that the adoption of these proposals and of the whole of the rules would be to the universal benefit of the electrical industry and to the application of electrical machinery in all countries.

Dr. C. C. GARRARD: I cannot quite understand the Dr. Ga lengthy arguments which have been put forward with regard to the reference, or standard, air temperature. It seems to me that this is only a roundabout and somewhat confusing method of fixing the standard temperature rise. It is clear, since it has been granted that the temperature of the cooling air during test has no effect on the temperature rise, that machines can only be compared with each other on the ground of temperature rise. Three possible I.E.C. ratings have been mentioned to-day, viz. the temperate zone rating (based upon the nominal air temperature of 35° or 40° C.), the torrid zone rating, and the northern or arctic zone rating. This is a very bad beginning for the establishment of a standard or international rating. Some people seem to have gone to great trouble to make meteorological investigations over the greater part of the world. This seems to me to be somewhat absurd since much greater variation of temperature may be found in one building or ship—say between the stokehole and deck, in both of which positions electric machinery may be placed. The idea appears to be prevalent that having fixed the limits of observable temperature it is possible to devise a rating which would ensure that this permissible temperature will never be exceeded. This is clearly impossible. It would be possible, of course, so to arrange the rating that in the majority of cases the highest allowable temperature would not be exceeded. My point is, however, that the method of referring to a standard temperature for cooling air is confusing. The real question is whether the standard temperature rise shall be, say, 60 degrees C. or 55 degrees C. Having fixed this, there would only be one rating, as of course there must be if it is to be an international rating. The table of limits of observable temperature given on page 245 would then be very useful to the user in determining what machine to use in any given circumstances. He

would know the surrounding air temperature, and this added to the standard temperature rise would give the final temperature which would be attained. He would then know from the table on page 245 whether the material of which his machine is constructed would withstand this temperature or not. In fact, this method of investigation must always be used. It is not possible to fix any standard rating so that the purchaser would be safe in installing in any position a machine purchased as being in conformity with such standard rating. Such action would have the result that instead of the factor of safety being higher the hotter the location, it would, in fact, be lower than in a colder situation. In conclusion, I think it would be much better to make it quite clear that we are simply aiming at fixing an international standard of temperature rise and that there will not be several I.E.C. ratings but only one.

Mr. N. B. Rosher: I consider that the work already done by the Commission in fixing the limits of observable temperature for the various parts of electrical machinery is of very great importance, but I agree with Dr. Kahn when he pleaded that the rating of machines should be no higher in the future than at present. If the Commission ultimately adopt 40° C. as the ambient temperature, the rating of machines will be considerably higher than at present. My objection to the higher rating is chiefly that a very large percentage of the motors used for industrial purposes drive line shafting to which additional machines are frequently added. If the motors used for these purposes are highly rated there will not be the same margin of power as at present. Of course it may be argued that this can and should be guarded against by installing a motor of liberal capacity for the work it has to do, but speaking from considerable experience I maintain that this course is not generally adopted unless the purchaser has expert advice. In any case the chief requirement of a motor is that it should prove reliable in service, and this is the more likely to happen if the machine is rated liberally rather than up to its maximum safe limit. It is gratifying to note that the present unsatisfactory condition of affairs as to overload, and the illogical permissible difference in temperature rise between protected and totally enclosed motors, will disappear under the proposed new rating. With regard to the table of limits of temperature for various parts of machines adopted by the Commission, it seems to me very undesirable that the figure for bearings should be as high as 80° C. It may not matter for large machines which are under constant supervision, although even there I think it too high. It is in the case of motors which are installed in out-of-the-way positions, or where an inspection is made at only infrequent intervals, that such a high limit as 80° C. is so undesirable. Should there be any little hitch in connection with the bearings of such motors, as is quite possible, the temperature would rise and the motor might easily break down if the ambient temperature approaches 40° C.

Mr. H. R. Hudson: I should like to draw attention to one point which, although only indirectly connected with this discussion, has very considerable importance in connection with the fixing of maximum permissible temperature rises. I refer to the employment of fans on the rotating parts of ordinary "protected type" and "enclosed ventilated type" industrial motors. Mr. Everest has stated that the I.E.C. standard of quality has now been established as regards the temperature and, therefore, the life of a machine, and also that provided the I.E.C. rating be specified, a buyer of standard machines could compare, without misunderstanding or possibility of mistake, tenders received from various makers, even from different countries. Now, every designer is familiar with the reduction in cost for a given temperature rise which is obtained by the use of well-designed fans on the revolving parts of motors of normal speeds, and this without an appreciable reduction of efficiency. We are, unfortunately, equally familiar with the fact that, in five cases out of six, motors are installed in such positions and under such conditions that after a few months' running the ventilating passages and the interstices between the armature coils of a fan-ventilated motor are so clogged with dirt that if a full-load test be taken the maximum temperature rise will be found to be 10 to 15 per cent higher than when the motor was first installed. This is not the case with machines relying on natural ventilation. Hence specifying I.E.C. rating would *not* in all cases establish a standard of quality either as regards temperature or life, unless accompanied by some proviso that the temperature limits shall not be exceeded when the machine is tested after a certain period of running under actual service conditions. Such an arrangement would of course be commercially out of the question, and it would therefore be very desirable if the Commission could see its way to define clearly the various types of machines. The Standardization Rules of the British Electrical and Allied Manufacturers' Association do not differentiate between enclosed ventilated machines with natural ventilation and enclosed ventilated machines with ventilation induced by means of a fan on the revolving shaft, but I certainly think that in the interests of the buyer and also from the point of view of placing all manufacturers of whatever nationality upon an equal footing when quoting for enclosed ventilated machines, it is most desirable that machines with natural ventilation should not be placed in the same category as machines with fan ventilation. The matter seems to me to be quite as important as discussing whether the maximum air temperature in the temperate zone should be taken as 35° C. or 40° C. I sincerely hope that the Commission will give the subject of the definition of types of electrical machines its earnest consideration.

Mr. H. M. Hobart (*communicated*): In the preliminary draft of a pending revision of the Standardization Rules of the American Institute of Electrical Engineers the plan has been followed of adhering to the I.E.C. Rules to the extent to which the latter have now been completed, and to incorporate their spirit in dealing with the classes of machines and the various features for which they do not yet provide. The preliminary American Institute draft divides rotating machinery into two groups, relating respectively (*a*) to machines for pressures up to and including 4,000 volts, and (*b*) to those for pressures above 4,000 and not exceeding 14,000 volts. For these two classes it is assumed that the internal drop in temperature will be respectively 10 degrees and 20 degrees. That is to say, it is assumed that there will be places in these machines where the insulation will be subjected to temperatures exceeding by 10 degrees and 20 degrees respectively the highest temperatures

Mr. Hobart which can be "observed" with the methods of measurement recognized in the rules. For stationary transformers the internal drop in temperature is assumed to be 10 degrees, irrespective of the pressure for which the transformer is wound. The construction of modern transformers is on such lines that the internal drop in temperature is no greater in a 100,000-volt transformer than in a 1,000-volt transformer. In fact, if anything, the small low-pressure transformers are of such compact construction as to lead to the liability of greater internal temperature drops than would occur in large extra-high-pressure transformers. However, the value of 10 degrees for the internal drop in temperature may be deemed entirely appropriate for all transformers. Were we to confine to mercury-thermometer measurements the methods by which the "observable" temperature should be obtained, these assumed internal drops would often be inadequate. But it is proposed to encourage the use of much more searching methods of arriving at the "observable" temperature, such as by the measurement of the resistance of the windings, or even by the use of embedded search coils, or thermocouples. In the preliminary draft for the American Rules the I.E.C. values for the highest permissible limits of "observable" temperature have been adopted. It has, however, been considered desirable to draw attention to the values of the "hot-spot" temperature, and it is proposed that the American Rules shall contain columns giving the values of these "hot-spot" temperatures in addition to the corresponding values of the highest permissible "observable" temperature. The values which have been internationally adopted for the highest "observable" temperatures represent approved practice for continuous running, if associated with such provisions as shall insure that they are never exceeded. A very small exception to this sweeping generalization is made. This exception relates to the rule that the duration of a test of a machine for continuous service shall be prolonged until the temperature of the machine and that of the cooling air does not increase by more than 1 degree per hour. The temperature rise at this stage of the test shall be taken as the "observable" temperature rise corresponding to continuous operation. As a consequence of this rule, the so-called highest "observable" temperature will, in reality, be exceeded by from 1 to 2 degrees according to the size and type of the machine. This excess may be reasonably considered as covered by the values allocated to the internal temperature drop. While these are taken as nominally 10 degrees and 20 degrees respectively, one or two degrees of this 10 or 20 degrees may be considered as reserved for meeting the above rule, the remaining 8 or 9 degrees on the one hand, or 18 or 19 degrees on the other hand, corresponding to the actual difference between the "hot-spot" temperature and the "observable" temperature.

This expression of approved practice as regards the limits of "observable" temperature requires to be accompanied by international agreement in the matter of an "ambient temperature of reference" in order to secure the commercial advantages of an international rating. For the American Rules the prospective international ambient temperature of reference" of 40° C. is adopted. Data of *shade* temperatures from all over the temperate zone afford ample evidence that no lower value could be adopted consistently with the international recommendation that the standardized limits of "observable" temperature shall never be exceeded. This recommendation is not only international but it has already been incorporated in paragraph 18 of the new standardizing rules of the Verband Deutscher Elektroteckniker, which include the following statement:—

"Die höchsten zulässigen Temperaturen sind in Spalte 2 angeführt.

"Es wird angenommen, dass die Temperatur der Umgebung 35° C. nicht überschreitet.

"Dementsprechend dürfen die Temperaturzunahmen die in Spalte 1 aufgeführten Werte nicht überschreiten." *

Although in these V.D.E. Rules the ambient temperature is taken as 35°, this is accompanied with the statement that 35° shall never be exceeded. Since the approved "observable" temperature rises set forth in the V.D.E. Rules are values which, when added to 35°, give the highest permissible "observable" temperatures, it is clear that when the ambient temperature is greater than 35° the highest "observable" temperature will be exceeded by an equal amount. *Shade* temperatures approaching and exceeding 35° are so common in all parts of the temperate zones that there is no escape from the conclusion that in the neighbourhood of electrical machinery the ambient temperature is frequently between 35° and 40°. To *declare* it to be 35° is futile if (as is the case) it *actually attains* values several degrees greater, since this will occasion the temperatures corresponding to approved practice at times to be exceeded by several degrees, which conflicts with the international agreement that the approved observable temperatures are to be considered as values which shall never be exceeded.

The work so far accomplished on the revision of the American Rules is chiefly due to Messrs. Lamme, Steinmetz, Merrill, Robbins, and Powell, the members of the 1912 sub-committees dealing with the revision. The 1913 sub-committee is at present engaged in drawing up sections dealing with "Efficiency and Losses," with "Performance Tests with Load," and with "Regulation." These are subjects which have not yet been included in the I.E.C. Rules, and it is the desire of the Committee having the matter in hand to endeavour so to frame these Rules as not only to conform with the most approved practice, but also to be on such lines as shall be in agreement with the best work already done in other countries. A great deal of standardization work has been done in Great Britain and in Germany, and it is desired to take this into careful consideration in all sections of the American Rules.

Mr. A. R. EVEREST (*in reply*): The discussion has brought out a few points on which some explanation seems necessary. With regard to the suggestion that a definition of commutation limits is needed, it may be said that the International Electrotechnical Commission has proposed to take up this question immediately following that of temperatures.

In connection with the point raised by Mr. Siebs as to

* "The highest permissible temperatures are given in column 2.
"It is assumed that the ambient temperature does not exceed 35° C.
"Accordingly the rise of temperature must not exceed the values given in column 1."

Mr. Everest. the desirability of allowing the same temperature limits on such dissimilar structures as commutators and slip-rings, at first it was proposed to allow higher limits for slip-rings, but they were finally reduced to those specified for commutators, the reason being that brushes of similar character are employed in both cases, brush deterioration largely determining the permissible temperature.

Dr. Garrard referred to three ratings, namely, for temperate, torrid, and arctic conditions. It is only proposed at present to establish an international rating suitable for temperate countries. Machines intended for tropical conditions would have to be rated specially, so that the limits of ultimate temperature given in the table on page 245 should not be exceeded.

Mr. Hudson mentioned machines arranged with fan ventilation, which become clogged and overheated after a short period of service. In connection with his reference to the Standardization Rules of the British Electrical and Allied Manufacturers' Association, it may be pointed out that those rules differentiate between machines according to the mesh of the screen placed over the ventilating openings, the intention being that those constructions which are liable to become clogged shall be rated not as ventilated but as totally enclosed machines.

Dr. Railing referred to variation in the cooling properties of the air according to its humidity. The difference between the heat-absorbing capacity per degree rise of temperature when saturated and when perfectly dry is about 17 per cent with air at 40° C. and much less at lower temperatures. Remembering that even on a "dry" day the humidity is usually from 60 to 80 per cent of saturation, it would appear that the actual variation between dry and wet days becomes negligibly small. But if the machine itself has become damp by storage in a humid atmosphere, it may show a lower temperature rise in operation until it has become thoroughly dried out.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF THE 8TH JANUARY, 1914.

Proceedings of the 560th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 8th January, 1914—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 18th December, 1913, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

Messrs. E. W. Moss and C. F. B. Marshall were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Member.

Hersfeld, Rudolf.

Associate Members.

Denham, John.
Eason, Alec Birks.
Evans, Stuart.
Field, Arthur Mottram Cox.
Oswald, William James.
Pressland, Clifford Thomas.
Tivey, John Proctor.
Wade, Charles Frederick.

Associate.

McKenzie, Ernest.

Graduates.

Carr, Francis.
Fasnacht, Harold.
Joseph, Fred Bernard.
Mavor, Albert John.
Morgan, Joseph.
Platt, Frank Cuthbert.
Simpson, Francis Augustus.
Smith, Allen Egbert.

Students.

Baker, Hubert George.
Bottone, Reginald Amadeus R.
Brunton, Theodore Stuart.
Dawes, Ronald Richard.
Field, Lance Henry.
Jones, Walter John.
Langridge, Archie William.
Mann, Frank Harris.
Odgear, James Edward.
Paul, Bangsidhari.
Singh, Prem.
Skevington, Francis Kerr.
Sleigh, Charles Crofton.
Vereker, Henry Connell.
Ward, Percy.

TRANSFERS.

Associate Member to Member.

Cartwright, Cecil Leonard.
Marsh, Francis Richard.
Maxwell, John Maxwell Scott.
Moore, Edward Ernest.

Associate to Member.

Ashman, William Henry.
Richards, Arthur Francis Ward.

Graduate to Associate Member.

Mann, Thomas Sidney Lanyon.

Associate to Graduate.

Waygood, Oscar Candish.

Student to Associate Member.

Archer, John Oliver.
Broadhurst, Francis Arkle.
Hollings, Gordon Alfred.
Le Feuvre, Charles George.
Manners-Smith, John Alexander.
Martin, Cyril Arthur.
Nadejde, Horia Toan, M.Sc. (Eng.).
Papazian, Hapet.
Potts, Thomas Frederick.
Roxburgh, Andrew Kean.
Taylor, James Ardern.
Thompson, John Lindley, M.Sc.

Student to Graduate.

Brennan, Leslie J.
Gray, Ronald.
Mittra, Kshitish Chandra.
Tisch, Walter Clements.
Wilkinson, Sam.
Wyatt, Esdaile.

A paper by Mr. B. Welbourn, Member, entitled "British Practice in the Construction of High-tension Overhead Transmission Lines" (see page 177), was read and discussed, and the meeting adjourned at 10.5 p.m.

REACTANCE AND REACTANCE COILS IN POWER CIRCUITS.

By E. P. Hollis, Associate Member.

(*Paper first received 29th August, and in final form 3rd December*, 1913; *read before the* Newcastle Local Section, *26th January*, 1914.)

Summary.

In this paper the author proposes to review the part played by inherent and added inductance in the phenomena that occur in electric power circuits.

Introduction.

One of the most remarkable events in the recent history of electrical engineering has been the complete change of opinion of electrical engineers on the question of the use of reactance in alternating-current circuits. Until recently engineers endeavoured to avoid reactance in all its forms; but it is now realized that reactance has virtues hitherto unsuspected, which if turned to account confer important benefits on electrical power supply systems. In 1907 the author had evidence of the general opposition to reactance on the usual grounds of the likelihood of resonance, when in a paper read before the Newcastle Local Section he advocated for certain purposes the insertion of reactance coils in alternating-current circuits. Reactance coils are to-day being used not only for the purpose then suggested, but also where their introduction has far more vital consequences.

In 1900 when the rotary converter first came into prominence, reactance proved a valuable auxiliary, and this was probably the first occasion on which large reactance coils were used in power circuits. The rotary converter at that time gave a fixed voltage ratio, and offered no inherent method of regulating the pressure on the continuous-current side. This disadvantage was soon remedied by inserting reactance coils in the low-tension alternating-current circuit. External reactance coils were often installed, but as patent rights restricted the use of actual coils it was found possible in the majority of cases to design the transformers with sufficient internal reactance to meet the situation without lowering the power factor too much.

The Need for Reactance Coils in Power Supply.

Recent progress in electric power supply has marked out for reactance coils a promising future, and it is probable that they will prove of assistance in solving some of the problems that beset engineers concerned with the operation of extensive power supply systems.

One of the most pressing of these problems is that of limiting the excessive current that may momentarily flow in the case of a short-circuit. There is also a problem to which the author attaches equal importance, but to which far less attention is paid, namely, increasing the stability of power systems so that they can better withstand internal disorders.

As is well known, the short-circuit current of a generator reaches far larger dimensions than might be supposed at first sight, for the true short-circuit current is very different from that shown by the ammeter in a short-circuit test at the works. The latter reading is of the order of from three to five times the full-load current.

It has, however, for some years been known that in the case of a generator in which no special care had been taken to ensure a high self-induction, the current rises at the first instant of short-circuit to something like 30 times the full-load current. What exactly happens on short-circuiting a large turbo-alternator has been discussed at some length in recent electrotechnical literature, so that the author will content himself with a few brief remarks on this question.

There are five main effects which play a part in determining the value of the momentary short-circuit current of a generator. These are the self-induction of the armature, the armature reaction, the generation of eddy currents in the rotor, the transformer action between the armature and field coil, and lastly the resistance and surge impedance of the short-circuit path. It is the self-induction of the armature that plays the leading part in limiting the short-circuit current. The first rush of current is controlled by little more than the self-induction of the armature and the resistance of the circuit, which act practically instantaneously in stemming the rush of current. The eddy currents and the armature reaction, however, are unfortunately very slow in taking effect at such a critical moment. On the other hand, the transformer action is also slow. The armature reaction gradually asserts itself, sometimes attaining its full effect only after 15 seconds or more, when the initial rush of current has passed and the damage is done.

The eddy currents too are dilatory in their counter-effect; they reach enormous values, however, both as regards current and voltage, and they have been observed to flash over in search of a new path. Eddy-current effects have been recorded equivalent to 2·4 times the armature reaction.

Little is known of the effects of transient resistance upon the short-circuit current, but since the pressure drop due to resistance would be 90 degrees out of phase with the inductive voltage, any increase in the resistance of the circuit would have to be extremely large in order to make itself felt in limiting the short-circuit current.

The phenomena in connection with the field flux are very complicated. The transformer effect at the moment of short-circuit is such as to send surging through the field coils a current which has been observed to have a peak equivalent to 10 times the normal field current. This change in the field current, and consequently in the field flux, appears to assist the armature current. One theory which has been advanced balances the effects of the eddy currents and the field flux changes against each other; but there appears to be no justification for such a theory. Apart from armature resistance, practically everything depends on the ability of the self-induction of the armature to limit the current. Recent developments in design have tended to reduce the self-induction of the armature,

with the result that in a modern turbo-generator, unless very special endeavours are made, the leakage reactance (*i.e.* that due to self-induction only) represents only from 10 to 15 per cent of the synchronous reactance measured on the short-circuit test. It is not surprising then that the r.m.s. value of the momentary current may attain 20 to 30 times the normal full-load value (*i.e.* have a short-circuit ratio of 20 to 30) as has been demonstrated by experiment. Nowadays, however, designers have paid special attention to increasing the self-induction of the armature, and by various devices have increased the ratio between the armature inductance and the whole inductance.

The part played by eddy currents and fluctuations in the field flux in damping the first few waves is, like that of the armature reaction, not very great. Nevertheless, they have a not inconsiderable effect on the short-circuit current. Taking the tests which have been made upon short-circuited generators, the values of the currents actually attained are less than would be observed were leakage reactance the only limiting factor. Indeed, there seems to be a transient reactance operating at the moment of short-circuit, which adds something like 60 per cent to the leakage reactance of the armature and reduces the current to a smaller value than it would otherwise have attained. This value is nevertheless high, and is shown by experiment to be of the order of 20 to 30 times the full-load current. The rush of current in the field coils which occurs in the case of a short-circuit may conceivably give rise to a breakdown in them.

If one considers the destructive power produced in the case of such a short-circuit, it becomes obvious that something should be done to limit the flow of current. Taking a power-supply system in which generating plant to the amount of about 50,000 kw. is in use daily, a short-circuit between phases near the power station might mean a current of 120,000 amperes, which of itself would exert sufficient mechanical force to cause serious damage to cables, busbars, and connections. On the switches, also, its action would not be negligible. Of course, while the closed circuit existed the power would be of small amount, but as the switch in attempting to cut off the short-circuit begins to open, the power rises to a high value. With the switch closed the current is 120,000 amperes, and the voltage negligible ; and with the switch open the current is zero and the voltage is the full phase value ; but between these positions there is a moment when the amount of power is exceedingly large. It can be expressed in kilovolt-amperes for one phase by half the product of the maximum current and the maximum kilovolts ; which comes to over half a million kilovolt-amperes. No doubt a specially designed circuit-breaker would deal with that amount of power, but the chances of trouble in a switch of standard design are very great.

It appears, then, that a good case can be made out for imposing some limits to the amount of short-circuit current. In many instances reactance coils are being successfully employed for this purpose.

Reactance Coils and the Stability of Power Supply Systems.

Apart from their ability to relieve the power station of the shocks and stresses due to short-circuits, reactance coils largely promote the stability of a system, and it will probably happen that when the time comes for the operation in parallel of distant large power stations reactance coils will become essential.

Between alternators working in parallel there is a continual interchange of current, which tends to keep the two machines in step. The current which flows, however, is not all available for promoting parallel running. As is well known, only its synchronizing component is so available, and anything that increases that component also improves the parallel running of the machines. The reactance coil does this, for the current flowing between the machines being more or less in quadrature with the main voltage, has to be brought more nearly into phase with the voltage before it can be useful in promoting synchronism. In the absence of adequate reactance the synchronizing component of this current is only small. The presence of reactance, however, greatly increases the value of this component. Usually the inherent leakage reactance of the machine sufficiently exceeds the resistance to ensure that machines in the same station run fairly well in parallel. The ratio of reactance to resistance deemed necessary for this purpose is about three or four to one. Where the machines have considerable resistance between them the leakage reactance is less than the resistance, and bad parallel-running results. Not only, then, will reactance improve the running of the machines in the power station, but it adds materially to the stability of the system as a whole by assisting the synchronous machinery at a distance—whether generating or motoring plant—at critical moments. Hitherto the reactance of the transformers and transmission lines has only been available for this purpose.

In other directions also reactance promotes stability. Schuchardt and Schweitzer's* experiments demonstrated that with adequate protection the generator speed did not drop more than 2 per cent on short-circuit. Moreover, the voltage of the generators does not decrease so much ; the liability of electrical machinery connected to the system to fall out of step is therefore lessened—a point of considerable importance.

Reactance and its Effect on the Continuity of Supply in Power Stations.

For some years attempts have been made to promote continuity of supply in power stations by adopting the so-called "unit" system of running. In a previous paper read before the Newcastle Local Section of the Institution, the present author, writing at a date when the system had never been put into operation in this country, discussed its merits and defects Actual experience confirms the views which he then expressed. But the unit system goes a very small way towards promoting the reliability of the system ; for unless the expenditure be very great the generators must run in parallel, either through the busbars or the network, and all the troubles incident to a breakdown on the busbar side of a grouped station are repeated in the case of a system operated on the unit principle. The boilers, too, must be operated in parallel.

Power-limiting reactance coils are valuable not only when inserted in the phase leads of the generator, but also between the busbar sections. If the coils are merely

* *Transactions of the American Institute of Electrical Engineers*, vol. 30, part 2, p. 1143, 1911.

inserted in the phase leads, when a number of machines are running in parallel with the "star-point" of only one machine earthed, that machine takes the whole of the current of a short-circuit between one phase and earth, and in consequence it has to withstand all the stresses. Should, however, all the generators be connected to a neutral busbar which is connected to earth through a resistance or reactance coil, the short-circuit current divides between all the machines, and while the portion taken by each machine may be comparatively small, the aggregate may attain undesirable dimensions.

Reactance coils inserted in the busbars, however, limit the amount of power which a group of machines can supply on short-circuit to a feeder the normal load of which is being supplied in part by another group of generators. The station busbars would be "ring" connected and a set of reactance coils would be placed between each group of machines. Thus the perfect unit system can be more nearly attained by using reactance coils.

The amount of reactance to be used between the busbars is determined by several considerations. First, it must be high enough to prevent a serious fall of pressure in its section in the case of a short-circuit on another section; and, second, it must not interfere to any appreciable extent with the current that must necessarily pass between the various busbar sections to accommodate changes of load or to promote synchronous running. Circumstances peculiar to every case fix the exact value of the reactance, for which 20 per cent * of the generator capacity of each section would be an approximate figure.

Reactance coils in feeder circuits naturally follow for limiting the power on short-circuit in underground and short overhead lines. In the case of interconnecting mains between power stations, reactance is also desirable to promote parallel running, especially where the resistance of the feeders is large.

Internal and External Reactance in Generators.

Whether internal or external reactance is to be employed in the case of a generator is a further ramification of the main problem. Dynamo designers have occasionally taken exception to the idea of external reactance, and have declared their ability to embody all the necessary reactance in the machine itself. That may often be a difficult matter for very obvious reasons, since the whole of the reactance, say 15 per cent, in order to be effective in preventing rushes of current in the case of short-circuits, must be of the leakage or self-inductive variety.

Apart from questions of design, it is evident that a considerable proportion of the inductance must be external to the machine. One of the duties imposed upon a reactance coil is that of protecting the generator itself from a heavy influx of power from the system in the event of a burn-out. Such a burn-out occurring near the terminals might rob the generator of all or a large part of the reactance on which it depended for its protection. So that in the event of the reactance being wholly internal little protection will be afforded to a broken-down generator, and at least some of the reactance must be external. Perhaps an equal division, internal and external to the generator, would meet most cases.

* The value of the reactance coil is most conveniently referred to in terms of the percentage drop of voltage across its terminals with full-load current flowing.

Reactance Circuit-breakers.

The heavy duties which the modern oil circuit-breaker is called upon to perform present severer difficulties as the size of the generating unit increases. So much so that cases are on record where two circuit-breakers have been installed in parallel. For rupturing heavy currents a "resistance" circuit-breaker was developed in which instead of the current being broken immediately, a number of auxiliary steps opened first and inserted a gradually increasing resistance until finally the main contacts opened and completely broke the circuit. In this manner the current was gradually reduced and the duty imposed upon the main contacts was lessened. Although theoretically sound, the principle introduced difficulties in practice. The power absorbed in the resistance caused a large amount of heat to be generated, and the problems of insulating such a resistance were not easy of solution. Reactance, however, is a preferable alternative to resistance, and it has been successfully employed in this direction. Instead of a number of steps, as in the case of a resistance, only a single step is employed. The reactance coils are so connected that they may be placed in series with the line, the load, and the main contacts; but with the circuit-breaker closed they are short-circuited by auxiliary contacts. These contacts are the first to open and thus connect the coils in series with the line and reduce the current before the main contacts separate. These main contacts then break the load-current at its reduced value.

Reactance Coils and the Switching-in of Generators and Motors.

The dangers attending the synchronizing of large turbo-alternators have long been recognized and the sticking or slow operation of an oil switch may imperil the safety of a large generator. In several instances abroad, operating engineers have gone to the other extreme, and by inserting reactance coils between the incoming generator and the busbars have freed themselves from the anxieties of synchronizing. These coils have been designed to allow the generator to be switched in when 180 degrees out of phase with the busbar voltage without undue stresses being caused. Under these circumstances it is unlikely that a machine unprotected by reactance coils would remain undamaged, since both the current and voltage conditions severely test the generator. The resulting pressure between the busbars and the generator would be twice the generator voltage, but the pressure wave would certainly not oscillate about the neutral axis. On the contrary, it might oscillate so far above it that the maximum pressure to earth would be four times the normal.

With the development of the so-called "self-synchronizing" synchronous motor, it is not improbable that reactance coils will be employed to limit the rush of current on switching in, taking the place of more complicated starting devices.

The Efficacy of Reactance Coils.

Assuming that some limit should be set to the amount of short-circuit current, it still remains to be shown that the insertion of external reactance can effect the desired reduction in current. Experimental results at the Fisk-street station, Chicago, clearly indicate that reactance coils do

materially reduce the short-circuit current. An observed short-circuit current of 30,000 amperes with no external reactance but 2 per cent of internal leakage reactance was reduced to 19,400 amperes by 3·93 per cent of external reactance, and to 15,800 amperes by 6·26 per cent. Durgin and Whitehead * have derived a formula from which the maximum short-circuit current can be calculated by simple low-voltage short-circuit tests. Applying this formula, curves have been obtained from which it is an easy matter to deduce the effect of a short-circuit with varying values of the reactance. Starting in a particular instance with a short-circuit current of 27 times the full-load value, 6 per cent of reactance would reduce it to 15 times, and 15 per cent to about 9 times, the mechanical stresses on the end-turns being respectively 729, 225, and 81 times the full-load value. The conclusion reached as the result of this investigation, namely that the total leakage reactance should not be less than 15 per cent, seems to have every justification.

As might be expected, it appears from Durgin and Whitehead's formulæ that the effect of resistance in circuit with a fault diminishes the part played by the reactance coils in limiting the short-circuit current. That, of course, is all to the good; it is in the worst conditions, when there is a very low fault resistance, or a low impedance of the system short-circuited, that the reactance coil is most needed. One fact in connection with the tests taken at the Fisk-street station is of considerable importance. The tests demonstrated that the presence of steam on the turbine in no way affected the results, *i.e.* the short-circuit energy came from the rotating mass of the machines. The author inclines to the opinion, then, that on a large power supply system, where there is not only the rotational energy of the turbines, but also that of all the other synchronous and asynchronous machinery, the short-circuit current must be far larger than the calculations and experiments on a single machine would lead us to expect.

Reactance and Third-harmonic Currents.

One of the earlier uses to which it was suggested to put reactance coils in alternating-current power circuits was that of limiting the flow of the third-harmonic currents between three-phase star-connected generators. To limit such currents many engineers have resorted to the earthing of only one generator "star-point." In order to limit the short-circuit current a resistance and now a reactance are included in the earth circuit. But this suggestion of using reactance was made in the early days when the possibility of troubles due to resonance were ever present in the engineer's mind. However, the reactance which is now embodied in the generator or inserted in the phase leads for quite another purpose, also serves to limit any third-harmonic currents that would tend to flow when all the "star-points" of the generators were connected together. The triple impedance offered to the third harmonics by virtue of their frequency is doubled, since the reactance of the phase windings and that in the phase leads have both to be traversed. Calculations based on the low figure of a 10 per cent total leakage reactance (not including armature reaction, which does not affect the third harmonics) show that the danger of the third-harmonic current reaching 20 per cent of the full-load current is remote, even when operating with widely differing values of the excitation. Such a current may at first sight appear dangerous, but in reality its effects are negligible. Taking as an example a 10,000-k.v.a. 11,000-volt generator, having a total leakage reactance per phase of 10 per cent external and internal, with a third-harmonic voltage equal to 10 per cent of the fundamental voltage between the star-points of the generator, the heating loss would be increased by 1 per cent. Thus a 10 per cent reactance inserted in the phase leads renders the third harmonic negligible; and even an 8 per cent reactance does all that is necessary in this direction.

Reactance and Regulation.

Increased reactance in a circuit with a lagging power factor naturally adversely affects the regulation. But this is a matter which is not so important as it was some years ago. In the past, specifications demanding good regulation have compelled the designer to force his designs and to produce a more costly machine. It has often been pointed out that good regulation is not an unmixed blessing, and that it is a big strain on the switchgear and the generator itself at the moment of short-circuit. Now, however, the situation is greatly changed. The development of the automatic regulator offers a solution, and a generator with poor inherent regulation can be made to give a pressure curve comparing favourably with the best that can be obtained from the most carefully designed good-regulating machine.

In a sense reactance improves the regulation, since at critical moments in the case of a short-circuit it helps to maintain the voltage when otherwise the pressure would have decreased and the synchronous machinery have fallen out of step.

Reactance in Transformers.

At first sight it might appear that the benefits conferred by reactance and reactance coils upon a generator should naturally apply, if not in degree at least in kind, to the transformer. This is, however, far from being the case, as the position is entirely different, and the premises which permit a successful application of reactance coils to the generator have little in common with those where such coils have to be considered for protecting transformers.

The problem of protecting a transformer against high-frequency surges is an old one. It has been found, as everybody knows, that these discharges flowing into the transformer break like a wave against a breakwater and expend their energy in the first few turns of the transformer winding, occasionally breaking it down. Reinforcing the insulation of the end turns has been successfully resorted to, but one would naturally inquire whether it would not be better to provide an external reactance coil to resist the on-coming wave. There can be no doubt that a special coil is more suited for the purpose, but it appears to introduce a concomitant source of danger which cannot be passed over without consideration.

A transformer possesses distributed capacity, inductance, and all the characteristics that go to form an oscillatory discharge; and not only would the reactance coil prevent abnormal waves from entering the transformer, but it would retain inside the latter all those oscillatory currents which either arise inside the transformer or come from the line, and are transformed to a higher pressure at the

* *Proceedings of the American Institute of Electrical Engineers*, vol. 31, p. 897. 1912.

point where the line is connected to the transformer. To remove all danger when using a large reactance coil it would be desirable to equip the transformer with a protective device across its terminals which would safely dissipate the oscillatory pressures. It would appear then that if the same protective effect of a coil could be secured by endowing the transformer with high internal reactance the latter method would be preferable. This point will be further discussed.

Up to recent years consulting engineers specified transformers with low reactance. They were in some way justified, for reactance was undesirable in a lighting circuit, but transformers for power purposes seldom escaped the same condition. Now, however, the position is reversed, and consulting engineers specify high reactance and obtain it. The interior of a transformer is, however, no place for a large amount of reactance. The duty of the transformer is to transform, and while the small percentage of reactance that may be desirable for the voltage regulation of not too greatly over-compounded rotary converters can usefully be embodied in the design of the transformer, the use of high internal reactance is undesirable. It may fail to achieve its object in one essential effect, and perhaps in two. In addition the eddy-current losses become largely increased.

The general idea underlying the choice of a high reactance in a transformer is that it will do two things :—First, it will limit the short-circuit current ; and second, by this limitation the internal mechanical stresses of the transformer will be reduced. It may be that neither of these objects are attained to the desired degree.

There are many methods of increasing the reactance of a transformer, either by an adjustment of the design without the designer going out of his way to include any special feature, or by introducing a special leakage path. A small amount of reactance can be secured in a transformer of standard design sufficient for most rotary converter work, and higher reactances up to 25 per cent are possible by introducing special arrangements, such as the use of magnetic shunts to increase the leakage flux. But where this high reactance obtained by magnetic shunts is inserted merely to minimize the destructive tendencies of the short-circuit current, then the transformer is not protected as it might be, since it is impossible to design a transformer with magnetic shunts which will maintain its reactance in the case of a heavy short-circuit current. Far too much iron would be necessary in the shunt to carry the very heavy flux, and the regulation at normal loads would be very bad.

In the external reactance no iron at all is of course used, an air core being employed in order to avoid this defect, so that high internal reactance may be useless for limiting the short-circuit current. Indeed, it is very doubtful whether most transformers would survive a "dead" short-circuit on their terminals if the full primary pressure were maintained, particularly if the short-circuit occurred at the moment when voltage was passing through its zero value, the flux then being a maximum. Cable breakdowns would occur at maximum voltage, so that stresses would not be so severe in that case.

On short-circuit, transformers have the advantage that they are able to count upon some of the generator reactance, although the full synchronous reactance could not take part in damping down the short-circuit current. The exact amount of this assistance depends upon the relation between the sizes of the generator and transformer.

Considering next the reduction of the mechanical stresses inside the transformer due to the use of high internal reactance, many consulting engineers have thought a high internal reactance meant that the internal mechanical forces would be low in the case of a short-circuit. Yet high reactance is no absolute criterion of the relative strength of the internal mechanical forces. Of two otherwise identical transformers, the one with the lower reactance may conceivably experience smaller mechanical stresses at the moment of short-circuit. Everything turns upon how the designer has obtained the high reactance which he desires. The easiest and most convenient method of obtaining a high reactance is to decrease the number of coil groups in the winding, the reactance varying inversely as the square of the number of these groups. But so does the mechanical stress,* and a detailed consideration of the question shows that the mechanical forces are not materially reduced. On the other hand, if the increased reactance be obtained by enlarging the distance between the secondary and primary groups—and it will be noted that a high-tension transformer has inherently a higher reactance than a low pressure one owing to the larger amount of insulation necessary giving a leakage path of larger area—then high reactance is attained which will have the same effect as an external reactance coil.

Reactance can only be relied on as a current-limiting factor so long as the iron paths which carry the leakage flux remain unsaturated ; high internal reactance does not improve the transformer—very often it will mean much greater eddy current losses—and there are a large number of transformer designers who would prefer to design their plant untrammelled by any need of attaining high reactance.

Summing up the merits and demerits of high internal reactance, it seems better to obtain any large amount by the aid of external coils, especially when the limiting of the short-circuit current is in mind. The risk of internal disorders may be considered remote or immediate, and if the latter view be accepted, steps would be taken to protect the transformer by a shunted discharger. Small reactance coils are usually immersed in the oil with the transformer.

Reactance Coils and Transmission Lines.

Inductance plays a prominent part in the characteristics of transmission lines. In long lines, the line inductance is co-responsible with the capacity for a large rise in pressure towards the receiving end of the line. Any load other than one with a leading current reduces this excess pressure considerably—an inductive load more than a non-inductive load—and the power factor alters throughout the line. With an inductive load and a leading power

* The reactance is calculated from a formula of the nature—

Reactance volts

$$= \frac{(\text{no. of turns})^2 \times \text{current} \times (\text{area of leakage path})}{(\text{length of leakage path}) \times (\text{no. of groups})^2} \times \text{constant.}$$

while the formula for the mechanical stresses takes the form (where all the groups are alike)—

Mechanical stress

$$= \frac{(\text{no. of turns})^2 \times (\text{current})^2}{(\text{length of leakage path})^2 \times (\text{no. of groups})^2} \times \text{constant.}$$

factor at the generating end of the line, the power factor increases towards the end of the line, reaching unity at some point prior to the end. It then falls to a lagging value at the load.

This excess pressure is a cause of anxiety in long lines, for the voltage regulation is bad. On switching in the line the pressure at the far end rises at least to its no-load value, which may often be 150 per cent of the generator pressure. This will occur apart from any surges, but frequently the no-load voltage will be exceeded and a pressure 200 per cent of that of the generator may be reached. The immediate effect of such a rise in pressure is that the insulators at the far end of the line become overstrained and may flash over. But the suspension insulator may be the strongest part of a system, so that the transformers will often be the first to break down if a failure occurs. By reducing the diameter of the conductor near the receiving end so that it is just above the critical value for corona loss for the maximum working pressure, the corona loss may be relied upon to relieve to some extent the over-tension of the line should the latter suddenly be deprived of its load. With varying loads, too, the pressure changes are great at the end of the line and are a considerable source of inconvenience.

To this difficulty has to be added that due to supplying the charging current to the line. At no-load this current often exceeds the kilovolt-ampere capacity of a single generator (say one-fifth of the total output of the station) with the result that two or more generators are kept running merely to supply a very small load. The remedy is simple, though it is doubtful whether it has yet been applied. Shunted capacity can be compensated for by shunted inductance,* and the best palliative would be a uniformly distributed inductance throughout the whole length of the line. This, however, is a counsel of perfection, and the best that financial considerations would permit would be a few reactance coils at intervals along the line. Preferably these should be automatically adjustable with the load, by methods discussed elsewhere in this paper, but non-adjustable coils would still serve. Except under special circumstances the power station is no place for these coils. By placing them along the line both the pressure rise and the heavy leading current are affected; but by putting them in the power station only the leading current is remedied, and then merely at the generator.

Apart from voltage regulation the introduction of reactance, series or shunted, may be used to increase the efficiency of the line and the maximum amount of power that can be transmitted.

A line with large inductance may take less power under short-circuit than on full load; indeed, this is a characteristic of the long-distance transmission line.

In transmission lines the conditions which prevent the use of iron in reactance coils for power-limiting purposes are not present. Iron-cored coils would be much cheaper and would lend themselves to several methods of automatic or hand adjustment which would not be open to coils with air cores.

The relations between the inductance and capacity, which play so prominent a part in shaping the transient phenomena occurring in transmission lines, are not discussed in this paper.

* In telephone work shunted capacity is compensated by series inductance (loading coils).

Constant Potential Transmission.

One of the developments that the future may hold is that of a large electrical network interlinked throughout and fed at numerous points at which opportunities for cheap power development present themselves. Such a system exists to some extent to-day on the north-east coast, and there is every likelihood that in other industrial centres this lead may be followed. In such a scheme under present conditions variations in pressure throughout the system are unavoidable. No matter how carefully the pressure-drops are calculated for the various portions of the network, calculations will be upset by inevitable temporary changes in the points at which the power is fed into the mains.

Voltage reduction is not a question to be treated lightly. Where it is recognized as inevitable, compensation can be effected in the ratio of the transformers supplying the load, but this means that transformers of varying ratio will be required all over the system; and even then where long distances are involved the difference of pressure between full and no-load will be large, the pressure of the generating station being supplied by shorter lines with practically no drop.

These and other considerations have given rise to proposals for constant-pressure schemes in which, however large and however extensive they may be, the voltage is maintained constant. The theory on which these proposals have been based is that since a leading current flowing through a reactance experiences a rise in pressure, this phenomenon can be utilized to give a constant-potential line by varying the amount of leading current according to the load. This theory, be it noted, premises the inclusion of a considerable reactance—no matter how it may have been obtained—in the line. The source of leading current of adjustable value can only be synchronous condensers, over-excited motor-generators, and (but not advisedly) rotary converters situated at various points about the system. That the current may be caused to flow in such a system from a point of lower to one of higher potential is no contravention of Ohm's law; for, of course, effective r.m.s. values are referred to. At any instant current can only flow from a point of high to one of low potential. Nevertheless, the r.m.s. value of the potential at the receiving end may be larger than the r.m.s. value of the potential at the power station owing to phase difference.

Constant-potential transmission calls for a large amount of reactance in the line contrary to orthodox practice, where reactance is avoided as productive of pressure drop. Most lines would not possess sufficient reactance, and therefore it would become necessary to add it in the form of series reactance coils. In addition, a frequency of 50 cycles would be preferable to one of 25, since it gives a greater reactance.

A system designed on these principles would have a number of remarkable operating characteristics. In the first place it would of course be the duty of the operating staff or of the automatic regulators to keep the voltage at any point constant by adjusting the leading current taken from the line by the synchronous condensers situated at

the various points. When a short-circuit occurred in any part of the line, in view of the fact that the short-circuit power would be less than the full-load power, there would be no general interference with the system. This is due to the fact that the short-circuit power would be limited by the reactance of the line—the reactance coils, if any, would be inserted at the generating end of the feeders—while for the load current the reactance is compensated by the leading current.

Faults would therefore be only local affairs, and since the reactance of the line, whether inherent or added, would have the effect of limiting the short-circuit current, the duty imposed upon the switches would be far less than in a scheme of orthodox design where the flow of energy is unlimited.*

The addition of line reactance together with the introduction of reactive power would appear at first sight to occasion an increased line loss. There is, however, no diminution of efficiency, since owing to the higher voltage the same work can be done with a smaller number of amperes.

Reactance Coils for the Protection of Motor End-turns.

In some instances reactance coils are used to protect the end-turns of high-tension induction motors at the moment of switching on. These coils are often of the ironless pattern, a few turns of copper strip wound in a helix or flat spiral serving the purpose. Coils with iron cores are occasionally used, the three phases being wound on a common laminated straight core. It is imperative in such cases that the greatest care should be taken to insulate the coils well.

Adjustable Reactance Coils.

The problem of larger adjustable coils is one that will have seriously to be tackled in the future. It presents itself in its most acute aspect in the design of coils for shunting a transmission line ; and the mode of adjustment which is found most satisfactory in this instance is to change the magnetic conditions. A continuous-current coil for superposing a continuous flux on an alternating flux might well be used to render the reactance coil adjustable. Without materially affecting the core loss the continuous current gives the iron a magnetic bias, and the reactance coil takes a higher magnetizing current than it would otherwise do. While this method was originally proposed for converting a transformer into a reactance coil, the author does not believe that the potentialities of this method of rendering reactance coils adjustable has yet been realized ; at least, he knows of no suggestions which apply to such a method.

Construction of Reactance Coils.

The construction of current-limiting reactance coils brings the designer face to face with a number of difficulties, the exact value of which it is not always easy to appraise. In addition to the severe mechanical stresses incidental to a short-circuit there are electrical stresses due to transient voltages, the precise value of which cannot be foretold. Not only have the reactance coils to limit the current, but they have to carry the current until the short-circuit is cleared ; and since with reactance coils the overload relays, if any, will be set high, it may be that the reactance coils will be called upon to carry the current for many minutes.

Owing to the circumstances under which the coils work, iron must be avoided in the construction, while in view of the strong leakage field, all solid metal-work in the coil will be a source of eddy currents and may become unduly heated and cause a fire. Steel bolts, for instance, must not be used.

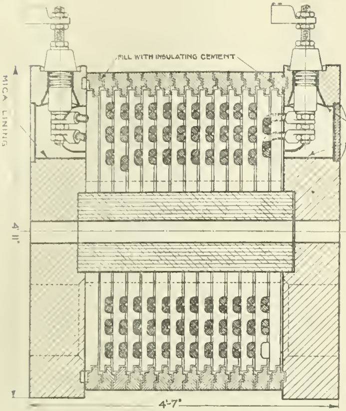
An 8 per cent reactance coil for a 10,000-kw. 6,600-volt generator would on full load have a pressure drop of 300 volts. A short-circuit on the generator busbar leads would result in a pressure of 3,800 volts, *i.e.* nearly 13 times full-load pressure, across the coil. Under such circumstances the reactance coil must still retain to the full its power to limit the current, and in order to meet this condition its magnetic circuit must not become saturated. In a reactance coil designed on orthodox lines, during short-circuit the magnetomotive force would be so great as to reduce the permeability of the iron to practically that of air. To enable the iron to remain unsaturated under this overload would mean such a low normal flux density that the use of iron becomes far from economical even if other electrical circumstances made it permissible. For this reason ironless reactance coils are the rule.

During short-circuit a large magnetomotive force is developed in these coils. In an 8 per cent reactance coil protecting a 10,000-kw. 6,600-volt generator there might be 44 turns. With full-load current the magnetomotive force is 38,000 ampere-turns, rising to 570,000 ampere-turns on a short-circuit current of 15 times full load. This is a large amount and calls for a careful disposition of any solid conducting material inside the coil.

In practice the coil takes several forms. In one, copper cable is wound under tension upon special wood supports which are bolted to a cylindrical concrete core. Where a single cable to give the requisite capacity would be too unwieldy, two are wound in parallel. According to its size the coil has three or five layers. The cables are quite bare, air being the insulator between adjacent turns. In view of the rise of pressure which must inevitably occur at the end-turns, each two end-turns are given greater clearance. Between each section or layer there is a space of several inches. Each end-turn is rigidly held by alloy clamps to the wooden supports. These supports are composed of strips of selected resin-filled maple having a disruptive strength of over 75 kilovolts per inch across the grain, and 30 kilovolts per inch along the grain. They are secured at their ends to the concrete core by radial brass bolts. Grooves are cut in the supports to receive the cable, which does not make direct contact with the wood. The copper and wood are separated by heat shields of asbestos. To increase the leakage distance between the layers of the winding and between the winding and the core, maple barriers are dovetailed into the sides of the supports. The supports themselves are not directly in contact with the concrete core, an insulating sheet separating the two.

* It is probable that switches will in the future be rated not alone on the capacity of the generator or feeder that they control, but upon the value of the short-circuit current—as limited by the reactance in circuit—which they are called upon to break.

The woodwork is finished with several coats of cream-coloured insulating enamel.



Sectional View of a Porcelain-clad Reactance Coil.

The core, which is hollow, is composed of a special mixture of cement, made by pouring into a collapsible iron mould. After removal from the mould the surface is levelled up and rubbed down, and is finally painted externally and internally with a number of coats of light yellow creosote paint. To take the external mountings and bracings the end of the core is provided with hexagonal or square extensions, while for lifting purposes a large nut or washer is received by a cored recess. For clamping the wood supports to the core, cast alloy sockets are embedded in the surface of the core. Into these sockets pass radial brass studs insulated by micanite. The nuts on these studs are insulated from the wood by heavy insulating washers.

A further form of reactance coil is the porcelain-clad coil, the chief characteristics of which are that the pancake instead of the drum winding is adopted. The cable is enclosed in a porcelain case, with the result that the coil is smaller than one with air insulation. The reactances are built up of horizontally-wound spirals (see diagram) supported in recesses formed in the porcelain arms which radiate from a central core of alberene stone to an outer enclosing well built up of porcelain segments. There are two heavy concrete headers, one at either end, and these are fastened to the wall by a number of mica-insulated brass rods passing through the headers and porcelain segments. The conductors are insulated and the arrangement of the interior of the coil gives a cellular construction which permits adequate self-ventilation.

A typical coil constructed on this principle was said by the manufacturer to give the following results :—

Number of turns, 34 ;
Reactance, 4·2 per cent (20,000 kw. 6,600 volts 25 cycles) ;
Ohmic resistance, 0·00195 ohm ;
$I^2 R$ loss, 6·05 kw. ;
Eddy current loss, 0·186 kw. ;
Total losses, 6·236 kw. per coil ;
Temperature rise, 33° C.

ELECTRIC TRAIN-LIGHTING SYSTEMS.

By T. FERGUSON, Associate Member.

(*Paper received 11th December*, 1913; *read before the* MANCHESTER LOCAL SECTION *27th January, and before the* BIRMINGHAM LOCAL SECTION *28th January*, 1914.)

Although many papers have been written on this subject, which is in itself of somewhat limited scope, the author in this paper proposes to discuss the problems which have to be solved in order to meet the requirements of service from the Railway Traffic Department's point of view; then briefly to outline the general schemes of regulation commonly employed, and finally to describe some of the more interesting types of train-lighting systems, making special reference to the particular methods adopted for overcoming the difficulties presented by the exigencies of service conditions.

It must be admitted that the railways in the United Kingdom have certainly made considerable progress in many ways during the last 20 years, but it cannot be said that they have perfected any system for the complete prevention of collisions. Terrible accidents of this nature still occur from time to time, often resulting in disastrous fires, thus intensifying the suffering and adding to the death-roll. Much has been said and written with respect to the comparative danger and safety of gas and electricity as a means of train lighting, and it has even been denied that gas adds materially to the fire danger in case of collision, but the fact remains that in nearly every case of fire after a collision on steam railways, gas has been used for lighting the carriages.

It is interesting to note that quite recently Major Pringle in his official report on the Aisgill disaster says:—

> "As regards illumination, I wish again strongly to urge upon railway companies the desirability of employing electricity as their standard illumination. It cannot be expected that all the gas-lighted vehicles can be replaced at once. The expense would be too considerable. But the policy of constructing all new stock with electric lighting and of replacing as early as possible the existing gas-lighted stock on main line and express services is in consonance with the trend of general practice all over the world, and one which is not impracticable from the point of view of expense."

The railways have been slow in adopting electric lighting for their passenger stock, but this reluctance to use electricity can hardly be for the reason that it is unsatisfactory as a means of illumination, or that there is no reliable system available, as there are many perfectly reliable electric-lighting systems on the market which sufficiently fulfil the requirements for ordinary working conditions. It would appear that the reason why electricity at the present date has not entirely superseded gas is one of capital expenditure.

When electric lighting was introduced on a commercial scale some 20 years ago it found lighting by compressed oil-gas already in total possession of the field, except in some few instances where lighting by oil-lamps was still in vogue. The gas-lighting plant installed represented a very large capital invested in gas-works, compressing stations, travelling gas-tanks for charging the gas cylinders of trains in outlying districts, and also, of course, the storage cylinders and general installations on the carriages themselves. If all this were done away with and electric lighting took its place, obviously the cheapest system to use would be to install high-speed steam-driven generators on the locomotives and merely equip the carriages with lamps and wiring, providing suitable cable connections between the carriages. This would of course mean equipping all the locomotives and carriages on the railways, and also providing those goods wagons which are used with passenger trains with wiring connections and couplings. This system is used to a limited extent in America, where it is known as the "head end" system.

There are many variations of the straight "head end" system, usually embodying the use of storage batteries on one or more of the vehicles, together with the necessary regulating apparatus. The object of this is of course to maintain the supply of lighting at such times as the locomotive is uncoupled from the train or the generating plant is inoperative due to breakdown, low steam, or other cause.

The simple "head end" system, although certainly the cheapest in first cost and subsequent maintenance, affords some inconvenience to traffic working, insomuch as the locomotives must remain attached to their trains for longer periods than are necessary with the gas-lighting system. Certainly a good deal of inconvenience in this respect could be overcome by providing the platforms of terminal stations with suitable lighting mains and plug connections to connect to the trains when they are standing alongside the platforms and waiting for their locomotives. There would still, however, be short periods when the locomotive with its generating set would not be available; for instance, when the trains are split up at junctions, and where very often several minutes are spent shunting different portions about the sidings. Suggestions have been made to equip such junctions with either collector rails or overhead wires connected to a lighting supply at the proper pressure, and so feed the carriage-lighting system through current collectors.

Besides the inconvenience of the "head end" system it does not lend itself to gradual conversion, and hence the lines upon which electric lighting systems have been developed are practically confined to the "individual unit" system, where each carriage carries its own

generator, driven from the axle, and also a storage battery to supply the lights when the train is standing.

There is an alternative course open in the case of block trains, and that is to light the complete train from one or more large axle-driven dynamos in the brake-van or vans, storage batteries and regulating gear of course being employed just as in the "individual unit" system.

The "individual unit" system is particularly well adapted to the requirements of the railways, as each coach so equipped is an independent unit, can be run anywhere on the railway, and has no storage tanks which require to be recharged at frequent intervals. The system can be introduced as gradually as required, the obvious way being to equip new coaches as they come out of the works and convert old gas-lighted rolling stock as opportunity arises. The capital cost of the system is of course much greater than that of the "head end" system, and the maintenance must also be considerably greater.

The author purposely refrains from giving any estimate of the cost of maintenance of electric lighting systems, as those alleged actual cost figures which have from time to time come to his notice have differed from each other so greatly as to make it more than doubtful whether any reliance can be placed on them. Then, again, so many of the railway companies use belt-slipping systems, and also in a great many cases double-battery equipments. Along with these are comparatively only a few of the more up-to-date single-battery systems, so that it becomes still more difficult to give any convincing estimate as to how economically the modern up-to-date single-battery systems may be maintained.

The author in this paper proposes to deal only with various examples of the "individual unit" system; but first of all he proposes to touch upon the problems which have to be solved, and then to describe some of the principal systems in the market, and how they meet the various difficulties.

In general it may be said that modern train-lighting equipments comprise the following apparatus:—

A dynamo slung from the underframe or truck frame of the carriage and belt-driven from a pulley on one of the axles. Means for regulating the voltage or output of the dynamo over a wide range of speed in both directions, and cutting it in and out of circuit at the right moment. A storage battery which is charged while running and supplies current to the lamps while the train is stopped or running slowly. Along with this is of course the necessary wiring, lamps, and fittings.

Traffic conditions demand that the equipments should answer the following requirements:—

1. The equipment may have to run on night service for long periods, hence the dynamo while running must generate more current than is required for the lamps, that is to say it must charge the battery while the lamps are burning, in order to make up for the current taken from the battery to supply the lamps while the train is stationary, and also to make up for the local losses which take place within the battery.

2. The equipment may similarly have to run on day service for long periods; hence some definite means for the adjustment of the output is necessary.

3. The same equipment may have to run on a suburban service having many stops and a low average speed, or an express service with few stops and a high average speed. It would be a great drawback if the ratio of the pulleys had to be changed when passing from the one type of service to the other. On most railways the traffic department is not slow to raise objections if this has to be done. A train-lighting dynamo should be capable of operating satisfactorily between speeds of 12 and 72 miles per hour in order to make it sufficiently flexible in working.

4. Machines are required both for coaches requiring heavy and light lamp-loads, and as it is inadvisable to use many different sizes some form of output adjustment is again necessary.

5. The storage battery cells must be as few as possible, on account of first cost, subsequent maintenance, and "dead weight."

6. The equipment must be robust, simple, strong, obvious in action, and easy of definite adjustment, so that poor-class labour may be able to maintain it.

7. The maintenance cost must be as low as possible both as regards the dynamo and the batteries.

8. It should be possible to switch the lamps on and off at will without affecting the voltage applied to the lamps remaining burning.

9. The output must be easily and definitely adjustable to suit all conditions of traffic.

10. The additional draw-bar pull on the locomotive due to driving the dynamos must be as low as possible, especially at high speeds.

11. Batteries which have got into bad sulphated condition owing to coaches lying idle must quickly pick up again when the coaches are placed in service.

In order to study the problem of meeting the several requirements it is convenient to refer to a very elementary diagram of an equipment, such as that shown in Fig. 1,

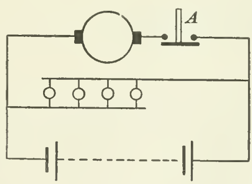


FIG. 1.

which represents the dynamo with its automatic switch A, storage battery, and lamps. As the usual pressure adopted is 24 volts, the battery will consist of 12 cells and will supply the lamps at a pressure of approximately 24 volts when the dynamo is stopped or running slowly. When the dynamo is running at sufficient speed to generate a pressure of 24 volts the switch A closes and the dynamo and battery are connected in parallel to feed the lamps. As the speed increases, the voltage of the dynamo will tend to rise and so take over the lamp load from the battery. At a certain point the battery will be merely floating and neither receive nor give out any current. As the dynamo voltage rises further, the battery will receive a charging current and the lamps will be over-run in volt-

age; a resistance must be inserted in the lamp circuit to absorb the extra voltage required for charging.

It is obvious that the dynamo may be regulated to give either constant current or constant voltage at speeds above the normal. In either case, if the battery is to be charged during lighting duty, the dynamo voltage must be considerably higher than the lamp voltage. In practice it should be at least 25 per cent above if the battery is to be kept in good condition. The difficult problem to be solved lies not so much in regulating the dynamo so that it gives constant current or constant voltage, but in dealing in the lamp circuit with the extra voltage necessary to charge the battery. Much effort has been concentrated on the problem of introducing and withdrawing in the lamp circuit compensating resistances in such a manner as to prevent fluctuations in the light.

It was this and other difficulties that early in the history of train lighting led to the adoption of the double-battery system diagrammatically represented in Fig. 2. The double-battery arrangement is practically

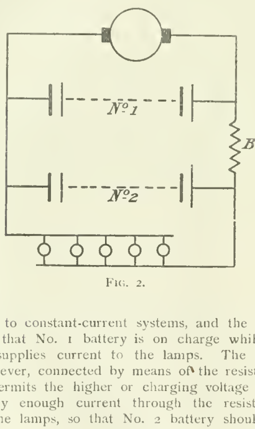


Fig. 2.

confined to constant-current systems, and the arrangement is that No. 1 battery is on charge while No. 2 battery supplies current to the lamps. The batteries are, however, connected by means of the resistance B, which permits the higher or charging voltage to send practically enough current through the resistance to supply the lamps, so that No. 2 battery should really float on the system. Any variation in the charging current will only alter the amount of current passing through the resistance, and No. 2 battery will have to supply more or less current to the lamps as the current from the dynamo rises or falls, as it may do owing to poor regulation, and certainly does do when the dynamo is switched into circuit and takes over the lamp current and battery-charging current, or vice versa.

It is obvious of course that when the voltage of No. 1 battery rises considerably, owing to the completion of the charge, or owing to a high rate of charging current, more current than the lamps require will flow through the resistance and No. 2 battery will begin to receive a small charging current, with a consequent rise of voltage on the lamps. It is also obvious that the effective storage capacity of No. 1 and No. 2 batteries is not equal to the combined rated storage capacity of the two, as practically only one battery is receiving a charging current; and further, when the train is standing the two are connected in parallel, with the resistance B short-circuited, so that the fully charged battery will partially discharge into the empty battery, with consequent double losses.

The battery efficiency is therefore very low. A well-known firm of storage battery makers state that "with most double-battery systems the efficiency is probably not more than about 5 to 10 per cent of the current generated."

Even the double-battery arrangement is not very flexible in operation as regards compensating for voltage when lamps are switched off or on, as the resistance is only absolutely correct for a given condition of lamp-load and battery charge. If a considerable proportion of the lamps are switched off, the voltage at the lamps will increase.

The arrangement, however, is successful in maintaining a reasonably steady voltage on the lamps when switching the dynamo in or out of circuit, and also under fairly wide variations of dynamo current and lamp load. It is accordingly very much used as it enables a fairly steady light to be maintained with a comparatively poor dynamo regulation and with quite crude and simple automatic switchgear.

The double-battery arrangement is without doubt expensive to maintain, and also very heavy, as each battery of 12 cells for an ordinary carriage would along with its cupboard and hangers weigh about half a ton. A system which employs only one battery must be considerably cheaper to maintain and may be cheaper in first cost, as the value of the battery saved is equivalent to a considerable amount of extra regulating apparatus or switchgear.

It has been pointed out above that the dynamo may be regulated for either constant current or constant voltage, and systems are, broadly speaking, divided into two classes, viz. the "Constant Current" and the "Constant Voltage" systems. In the former the dynamo generates a steady current and its voltage is kept steady by the battery; in the latter system the dynamo maintains a constant voltage and the current output varies according to the state of the battery and the lamp load. Variations within these broad definitions may of course exist. For example, the dynamo may be regulated to give a constant charging current to the battery independent of the lamp load.

In the constant-voltage system the charging current to the battery falls off as the battery charge proceeds, so that overcharging is not usually obtained. Batteries, however, should be fairly often charged to the "gassing" point in order to keep them healthy, but a steady voltage high enough to "gas" the battery will give an excessive charging current at the commencement of the charge. It is accordingly much better to raise the charging voltage as charging proceeds. This may be done by using a resistance in series with the dynamo in constant-voltage systems, as it has the effect of raising the voltage at the battery terminals as the charging current diminishes, the increased voltage being, of course, due to the diminished drop in the resistance. With the constant-current system, however, this is what actually happens automatically, and the voltage on the lamps will vary to that extent.

In Figs. 3 and 4 charging curves are shown for constant voltage and constant current respectively. If the charging voltage is gradually raised as charging proceeds, a curve nearly similar to the constant-current charge of Fig. 4 is obtained. This curve shows the rise in voltage which takes place, and it will be seen that it is quite small over long periods, so that the variation in lamp voltage due to this cause will also be small.

In the author's opinion a constant charging voltage is not desirable, for the reasons given above. There is the

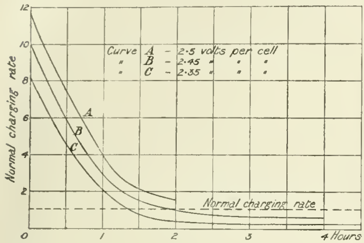


FIG. 3.

further disadvantage that a comparatively small variation in voltage will give a large difference in current. Fig. 3 shows the charging current curves for a battery at 2·35, 2·45, and 2·5 volts per cell. These curves show a high current charging-rate at first. If one cell in a 12-cell battery should become short-circuited, as sometimes happens, the current is considerably increased, since the battery is receiving too high a voltage per cell. On the other hand, a bad or dirty connection between the cells will reduce the current below what it ought to be for

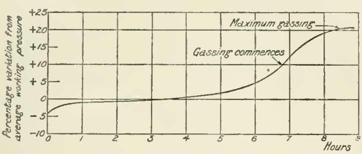


FIG. 4.

proper working. Further, a battery which has become badly sulphated, due possibly to a coach lying idle for a long time, will, on being put on charge, very rapidly increase in voltage, taking comparatively low current, even at first, and in a short time the current will have dropped to practically nothing, so that when the dynamo is stopped the battery has really got no charge worth speaking of, the result being that it goes from bad to worse.

It is in such points as these that the constant-current system has up to now proved the more practical system, and has been much more universally adopted than the constant-voltage system. With the constant-current system the current need not be adjusted to within 10 or 15 per cent, as a variation to this extent—or even to a greater extent—will not appreciably affect the battery-charging voltage, and all that will happen is that the battery will take a longer or shorter time to charge. In the case of bad connections between the cells, or sulphated cells, the dynamo voltage will rise sufficiently to maintain the constant current, and the sulphates will become reduced and the battery charge maintained—it is true, of course, at the expense of a slight rise in voltage at the lamps, but this is better than crippling an expensive battery, especially at the present time when metal-filament lamps, which admit of wide temporary variations in voltage without real detriment to the lamps, are in universal use.

It will be further noted from the curve in Fig. 4 that when the battery becomes fully charged the voltage increases very rapidly. At this point it is advisable, although not absolutely necessary, to cut off the dynamo or at least reduce the rate of charging, and advantage may be taken of this quick increase in the voltage to operate some form of overcharge preventer system, examples of which are described later.

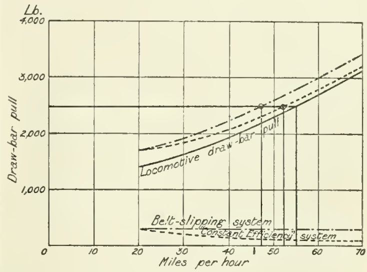


FIG. 5.

In connection with the subject of the extra draw-bar pull imposed on the locomotive by the use of electric train-lighting systems, it should be said that in both the constant-current and constant-voltage systems the draw-bar pull will decrease as the speed of the train increases. It should in fact be inversely proportional to the speed. Exception, however, must be taken to belt-slipping systems where the draw-bar pull remains constant, the power required to drive the dynamo being proportional to the speed, and the difference between this power and that required at the normal full-load speed being absorbed by the belt.

For any particular speed the constant-current system will offer the same draw-bar pull whether lamps are switched on or off and whatever is the state of the charge of the battery, until such time as the overcharge preventer may trip the dynamo out of circuit or reduce its output.

In the constant-voltage system the draw-bar pull will be high when the lamps are burning and the state of the battery is low, and will fall away as the battery charges up or the lamps are switched off.

Fig. 5 represents the draw-bar pull on level straight

track of a locomotive hauling 10 average coaches weighing altogether 300 tons (Armstrong). The extra draw-bar pull required by the dynamos for 8 coaches is also shown (2 coaches are assumed to be brake-vans without dynamos). By superimposing the added draw-bar pull on the train curve it will be seen that with a locomotive exerting a draw-bar pull of 2,500 lb. the speed of the train is reduced from 55 miles per hour to 52 miles per hour, or in the case of belt-slipping systems to 48 miles per hour. This curve is calculated for a total of 400 candle-power of metal-filament lamps per coach absorbing 1·25 watts per candle-power; this represents 21 amperes at 24 volts. Assuming the dynamo is giving 28 to 30 amperes at 30 volts (0·9 kw.) and taking the dynamo efficiency at 65 per cent, each coach requires 1·9 or, say, 2 h.p. to allow for belt transmission loss.

With most modern systems the efficiency at all speeds is practically constant; hence the draw-bar pull falls off as shown. However, with belt-slipping systems, as mentioned before, the draw-bar pull will be constant. In this case it is assumed that the dynamo is generating the above current at a speed of 20 miles per hour and above.

A study of the Patent Office records and of the literature on the subject will show that a large number of systems have been proposed, and many put on the market at one time or another. Some of these are as follows:—

- Beaumont and Still.
- Bliss (United States Light and Heat Company).
- Buttner.
- Brown Boveri (Old system—Aichelle).
- Brown Boveri (New system).
- Consolidated Light and Heat Company, U.S.A. (several forms).
- Gould-Simplex (U.S.A.).
- Grob system (Pintsch Gas Lighting Company).
- Leeds Forge Company.
- Leitner-Lucas.
- Moskowitz.
- Mather & Platt (Rosenberg dynamo).
- Newbold, U.S.A. (made by Adams Westlake Company).
- "Safety" system (U.S.A.).
- Siemens.
- Silvertown system.
- J. Stone & Co.
- Tudor Accumulator Company.
- Verity-Dalziel.
- Dalziel's Improved Constant-voltage system.
- Vickers-Hall.

Several of these have now practically dropped out of service, but there still remains a very fair number of systems from which the railway companies can make a choice. The author proposes, however, to describe and discuss only a very few of them.

Stone System.

As Messrs. Stone & Co. are practically the pioneers of the "individual unit" system, it is natural to commence by reference to their system. This is so well known that a detailed description is hardly necessary, but a few general remarks may be of interest. The dynamo in the Stone system is designed to work on the constant-current principle, and nearly all their equipments employ the double-battery system, whilst all the switches used for the automatic switch operation are controlled by means of a centrifugal governor contained under a dome cover fixed to the dynamo. The dynamo is in reality a torque-regulating machine, inasmuch as its output depends on the torque that the belt is able to transmit to the pulley by virtue of the frictional grip between them. The dynamo is hung pendulum fashion, and the belt is of such a length as to displace the centre of gravity of the dynamo from the vertical, and so keep a nearly constant tension on the belt. The voltage of the dynamo is determined by the battery, hence the current cannot increase above a definite amount, or the belt would slip. In other words the speed of the dynamo does not rise above full-load speed, however much higher is the speed at which the belt runs.

As the dynamo does not possess any other regulating device, it becomes a very cheap and simple machine, but obviously must possess the disadvantage of depending for its regulation entirely on the coefficient of friction existing at any particular time between the belt and the pulley. Hence the output will vary as the condition of the belt changes. For example, a new belt may be sticky on the surface and grip the pulley hard. In course of use, however, its surface will become glazed, and for a given belt tension the output would therefore be very different. Another disadvantage is that the dynamo inspectors cannot readily estimate what current the dynamo will give without making a run in the coach with a meter in circuit after any adjustment of the belt tension.

The waste of power at high speeds is also another serious drawback. If an equipment were geared to give its output at a reasonably low speed, say 15 miles per hour for a suburban service, the waste of power would be very great if the same equipment were run on express service without altering the pulley ratio. Taking for example a dynamo generating its full load of 30 amperes at 30 volts at a speed of 15 miles per hour, the horse-power input (assuming an efficiency of 67 per cent) would be 1·8 h.p. At 60 miles per hour the output is exactly the same, but the input is four times the above amount, namely 7·2 h.p. The extra waste of power absorbed by the belt is therefore 5·4 h.p., and the efficiency at that speed is therefore about 17 per cent. This is an excessive amount of power to absorb by the belt, and in order to save as much as possible wear and tear, and also the waste of power, it would be advisable to gear the dynamo for a lower speed ratio for express service, say to make it give full load from about 25 to 30 miles per hour for this class of working, while for low-speed suburban service it could be geared to give full load at a lower speed.

The question of the extra amount of coal burnt in the locomotive fire-boxes due to train-lighting equipments has exercised the minds of railway officials, with the result that more than one of the leading railways have made elaborate running tests with and without the dynamos coupled in order to ascertain the coal consumed for electric lighting. Generally speaking, in making coal-consumption tests it is found that there is a greater difference in the amounts of coal burnt for any two similar journeys than for similar journeys made with and without the dynamos coupled. In fact some journeys will show less coal burnt with dynamos

running than without them. This may be understood when it is realized that the total horse-power required for the dynamos will generally average something like 5 per cent of the total power exerted by the locomotive, even with belt-slipping systems, and the total coal burnt may easily vary more than that percentage owing to differences in the direction and strength of the wind.

An easier and more accurate way of making estimates for the extra coal consumed by the dynamos is to test or estimate from the speed curves of the train the total dynamo output in kilowatt-hours, and from that deduce the amount of coal consumed. In a paper read before the Institution of Civil Engineers * an account was given of such a test. With some of the more modern systems the power consumption is naturally much less than with belt-slipping systems, hence the extra coal consumed becomes considerably reduced.

In spite of the disadvantages inherent to belt-slipping regulation, the system of Messrs. Stone & Co. has maintained its lead in face of severe competition from manufacturers of other systems, and this system undoubtedly operates satisfactorily. This is probably due to the fact that its action is quite obvious and easily understood; also that it is a constant-current system, and as such can be maintained by comparatively poor-class labour, since it does not require any particular nicety of adjustment.

Leeds Forge Company's System.

The Leeds Forge Company's system is designed to avoid the disadvantages of belt-slipping regulation, whilst preserving its simplicity, robustness, and directness of action. The author is particularly interested in this system, having designed and developed it.

One of the main considerations in train lighting is low maintenance cost, and as storage batteries have about the highest rate of depreciation and maintenance of all electrical apparatus, it goes without saying that a system to be economical should be a single-battery system.

The Leeds Forge Company's system belongs to the "constant current" class, and accomplishes its regulation by means of the torque required to drive the armature. As the speed increases, the driving torque serves, by means of a cam, to thrust the armature bodily along its shaft in an axial direction from its normal position in the field, the thrust being resisted by a suitable spring. The armature with its commutator is mounted upon a sleeve which is free to slide on the driving shaft; and it is driven by a pin on the sleeve provided with a roller that works in a spiral cam-shaped groove cut in the shaft. This pin, when the shaft is rotating, bears against the side of the slot and so causes the armature to rotate with the shaft.

The power required to drive the dynamo cannot alter, as the pin has a tendency to ride along the slot; and since the shaft is fixed in its bearings this causes the armature to be pushed along the shaft out of the influence of the field magnet poles. This is done against the force of the regulating spring. As the speed increases, the armature is moved further out of the field: similarly as it decreases the armature moves back into the field. The spring is provided with an adjusting nut, so that the output can be varied by altering the initial compression of the spring, and an output scale is provided marked in amperes, so that the dynamo attendant can readily adjust the output to a definite figure.

The slot in the sleeve is cut in both directions, so that the action is exactly the same in whichever direction the dynamo runs. The change in polarity is taken care of by fixing the brushes on a brush-rocker disc, which is mounted on bearings attached to the rotating part.

Regulation by withdrawal of the armature from the field enables a very wide range of speed variation to be obtained with a minimum of sparking and with a maximum stability of the field, as the ratio of the field-magnet ampere-turns to the armature ampere-turns, instead of becoming lower when the speed increases as in the case of regulation by weakening the field, in effect increases, because the magnetomotive force at the air-gap increases when the armature is thrust out of the field, owing to the diminished drop of magnetomotive force in the iron circuit.

In addition to this, the lead of the brushes is automatically increased with the speed. This is very simply accomplished by making the fixed stop for the brush-rocker reversing gear tapered instead of parallel, so that when the armature slides out of the field the brush-rocker is advanced. The range of speed obtained is very wide; the dynamo comes into action at about 450 revs. per min. and runs as a self-regulating machine up to its maximum safe speed. This limit is 3,000 revs. per min., although the dynamo would regulate beyond this speed. Assuming 42-in. carriage wheels and a pulley ratio of 5 to 1, a variation in speed of 11¼ to 75 revs. per min. is obtainable, hence a carriage can be used indiscriminately for slow or express trains without changing the pulleys and without waste of power. The action of the machine is obvious and the adjustment of output easy, so that the system is adapted to be easily maintained by unskilled labour.

The automatic switchgear for switching the dynamo in and out of circuit and for introducing the voltage compensation into the lamp circuit when the battery is charging while the lamps are burning, consists of two solenoid switches with resistances. A complete diagram of connections for the system, including the windings of the solenoids, is shown in Fig. 6.

One switch controls the dynamo and the other the lamp circuits. The "dynamo" switch merely serves to connect and disconnect the dynamo from the battery and lamps when the dynamo voltage reaches or falls below the battery pressure. It is of the usual type with shunt and series windings and requires no further description except to mention that in its "down" position it short-circuits the series winding of the "lamps" solenoid.

The "lamps" solenoid switch, however, possesses several novel features with regard to regulating the pressure on the lamps. When the dynamo is stopped, the dynamo switch is open and the lamps receive current direct from the battery, the resistance 7–1 being bridged over. After the dynamo starts running, the dynamo switch closes at the right voltage and then the dynamo begins to take over the lamp current and relieves the battery. When its voltage has risen high enough to charge the battery, then—and only then—is the bridge over the resistance removed in steps and the

* R. T. Smith. "Electric Lighting of Railway-Trains: the Brake-Vehicle Method." *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 187, p. 142, 1911–12.

balancing connection 7–8 established via the main switch. The lamps are then connected across 10 cells receiving the charging voltage, so that the resistance 7–1 need not be altered when lamps are switched in or out. This saves a lot of complication of wiring and resistances when arranging the carriage lighting with individual lamps, each on its own switch. When the normal number of lamps is burning the I R drop in the resistance balances the charging E.M.F. of 2 cells and no current flows in the balancing wire. If more lamps are switched on, the difference in current between the normal lamp current and the new lamp current will flow along the balancing wire. The net result is—so far as the lamps are concerned—that their voltage is practically unaffected by switching lamps in or out; and, as regards the battery, the two end cells will either receive a little more or a little less charging current

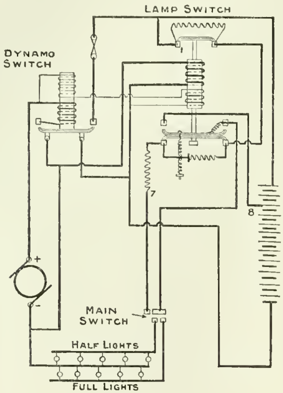


FIG. 6.

than the remainder, depending on whether more or less lamps than the normal are switched on. In practice this arrangement works very well and the end cells do not appear to suffer any inconvenience even after several years' service.

It will be seen from Fig. 6 that the lamps solenoid is provided with series and shunt windings, the series winding being in the battery circuit only. A current which charges the battery flows through this coil to assist the shunt winding, while a discharge current from the battery to supply the lamps acts in opposition to the shunt. Therefore until the voltage of the dynamo is high enough to supply a charging current to the dynamo the solenoid switch remains down. When the dynamo, besides feeding the lamps, begins to supply current to charge the battery, the series coil acting in conjunction with the shunt, lifts the plunger until the stop A comes in contact with the lower switch bar. The upper switch bar being lifted, the first step of resistance is inserted. When the charging current increases, the plunger will overcome the force of the spring, and owing to the position of the spring will tip up the switch bar across the left-hand bottom and the right-hand top contacts, thus inserting another resistance in series with the first. The leverage is now in favour of the spring, and the last step is therefore not made until the current has further increased. The switch bar is then tipped across the top contacts, inserting the last step of the resistance and establishing the balancing connector. With this novel arrangement of solenoid and spring the switching movements are effected by means of a single solenoid with a comparatively small travel. When the dynamo slows down below the minimum speed the charging current falls and the switch goes through its movements in the reverse order.

The best feature of any constant-current system is that it ensures the charging of the battery eventually to the "gassing" point, and thereby gets rid of any sulphates which may be formed on the surface of the plates. The objection is sometimes raised against it that it overcharges the battery. Admittedly it may under certain circumstances; moreover a too long continuance of a gassing charge will tend to scrub the surface of the plates and boil away the acid. It is, however, easy to avoid this by using the over-charge preventer referred to above. Most overcharge preventers consist of a relay switch connected across the battery, which acts at a certain predetermined voltage and either cuts the dynamo out of action altogether or reduces its output. The voltage for the overcharge cutout is indicated in Fig. 4.

The Leeds Forge Company use a small solenoid switch to break the dynamo field, thereby causing the machine to stop generating and the dynamo switch to drop out. The winding of this solenoid switch is connected across the battery via a small and simple switch which breaks contact when the dynamo stops. In this way a very reliable action of the solenoid is obtained, and the device does not depend on any delicate adjustment for releasing voltage when the battery voltage falls, as the solenoid plunger having been pulled "home" remains there until its circuit is severed by the dynamo stopping. Lost motion is provided between the solenoid plunger and the switch bar, so that the opening of the field is decisive. A similar arrangement of the plunger and spring to that employed on the lamps solenoid may be used to discharge the field on breaking.

MATHER & PLATT SYSTEM.

Messrs. Mather & Platt also adopt what is practically a constant-current system and use Dr. Rosenberg's patented generator. They usually prefer to employ the double-battery method, although they state that under some circumstances they are prepared to use a single battery. A diagram of connections of the system is shown in Fig. 7.

Dr. Rosenberg's dynamo is well known and has been frequently described in connection with train lighting. A brief résumé of its action may, however, not be out of place here.

The armature is an ordinary continuous-current one, revolving in a bi-polar field. The ordinary brushes are short-circuited, and a pair of extra brushes placed on an

axis at right angles to that of the short-circuited brushes are used to supply the current. The field poles are large and are provided with a small shunt exciting winding, which is connected across the battery and establishes a flux passing through the armature vertically. Rotation of the armature in this field produces a current through it via the short-circuited brushes, called the "aid" brushes. This armature current produces at right angles to the primary

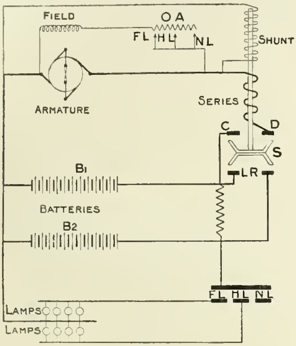


Fig. 7.

flux a secondary flux the path of which is through the pole shoes and the armature itself. The rotation of the armature in this secondary flux produces a difference of potential between the extra brushes, which are the main terminals of the dynamo. The component of the armature current which flows to the external circuit via these brushes produces a magnetomotive force opposing that of the shunt

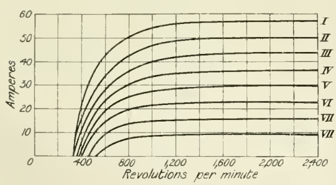


Fig. 8.

windings, and its value depends on the strength of the external current. This gives a similar effect to counter-compounding in an ordinary dynamo; but the effect is produced by means of the armature itself. The result is that with constant shunt excitation the current output curve will have the shape shown in Fig. 8. A number of different curves are shown in that figure corresponding to different values of the shunt excitation; and in Messrs. Mather & Platt's system this adjustment of output is provided for by varying a resistance in the shunt-winding circuit. Usually the hand-operated main-lamp-circuit switch is arranged at the same time to vary the shunt resistance so as to reduce the output when the lamps are switched off.

The main point in the dynamo as regards train lighting is that it does not require any pole-changing mechanism in order to retain the same polarity at its terminals when its direction of rotation is reversed. The reason is that the shunt excitation remains in the same direction; hence the "aid" current will be reversed and so give the required working field in the necessary direction for maintaining the original polarity.

Messrs. Mather & Platt usually suspend the dynamo under the coach by links from the end sill of the bogie truck, the tension in the belt being obtained by an adjustable spring. The lamps are switched on and off by means of a barrel switch, which controls two lamp circuits, one being switched on for "half light" and the other added for "full light." At the same time the necessary switching of the shunt resistance is done in order to alter the output of the dynamo. The same barrel switch can also be made to interchange the batteries.

This system being a double-battery system takes care of the lamp voltage by means of the No. 2 or "floating" battery, in the manner referred to previously.

Vickers System.

Another example of constant-current operation is the latest system adopted by Messrs. Vickers, Limited. This is the "D.L." system of the Consolidated Lighting and Heat Company, U.S.A. The dynamo is a shunt-wound machine, and when the direction of motion of the carriage is reversed the correct polarity is maintained by means of a reversing brush rocker. The current is kept constant by means of a solenoid-operated automatic rheostat, the rheostat contact arrangement of which consists of a sector rolling on a flat track formed by the terminal studs that are connected to the resistance. The solenoid has one operating winding in series with the battery, and is provided with an adjustable diverter in order that the output of the dynamo may be adjusted. A single battery is used and the difference between the dynamo and lamp voltages is taken care of by another solenoid-operated automatic rheostat of a similar type to the first, except that the solenoid winding is a shunt winding connected across the lamps. An over-voltage relay is also used for preventing over-charge of the battery. When this relay acts, it switches current on to an extra shunt coil on the dynamo-regulating solenoid so as to assist the main winding and cut down the dynamo current. This system does not possess any particular features beyond those already mentioned, of using two separate regulators, one for controlling the dynamo and the other for controlling the lamp voltage.

Tudor Accumulator Company's System.

This is also a single-battery system on the constant-current principle. Regulation in this case, as in the Rosenberg dynamo, is accomplished by the windings of

the dynamo itself, and the characteristic output curve is very similar (see Figs. 8 and 9). The dynamo is reverse-compounded in the ordinary way, so that a separate pole-changing device is necessary. The series field-winding is provided with an adjustable diverter resistance.

The pole-changing arrangement adopted by the Tudor Company consists of a movable brush-rocker mounted on bearings on the shaft itself.

Both the Tudor Company and Messrs. Mather & Platt follow the same practice in varying the shunt-field excitation when the lamp-circuit hand switch is operated in order to alter the dynamo output as lamps are switched on or off. The Tudor Company's practice, however, in absorbing the difference between the dynamo and lamp voltages differs from that of Messrs. Mather & Platt. The former company employs special hot iron-wire resistances for this purpose, and these are permanently connected in series with the lamps.

The diagram of connections for the Tudor system is shown in Fig. 10. On this diagram are shown the automatic cut-in switch A, the overcharge preventer B, the

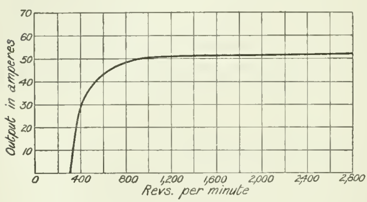


FIG. 9.

series diverter G, and the shunt-field resistances K, M, P, and R. The hot wire resistances for the lamps are also shown adjacent to the latter. The output of the dynamo is adjusted by means of the diverter on the series winding, this being necessary in order that the dynamo may accommodate itself to various conditions of service and lamp loads. The hot wire resistances absorb the difference of pressure between the dynamo and lamp circuits and also any variations in pressure that may occur on the system. These iron-wire resistances are enclosed in glass globes from which the air is excluded and hydrogen gas introduced, and they are run at practically a dull-red heat. At this temperature iron wire increases in resistance very rapidly with an increase of current, so that a considerable increase in voltage will make but little difference in the current passing through the resistance; hence the resistances act as a protection to the lamps. They possess, however, the disadvantage that they absorb a considerable amount of energy; in fact, the Tudor Company use a 15-cell battery to maintain 24-volt lighting, as against 12 cells used by other single-battery systems. This again requires a dynamo pressure of about 38 to 40 volts for charging the battery. Apart from the disadvantages of the extra maintenance involved by the additional storage cells and the special resistances and the losses therein, the use of hot wire resistances simplifies the problem of dealing with the difference between the dynamo and lamp voltages.

Prevention against overcharging the battery is taken care of in the usual way by a solenoid-operated switch, the windings of which are connected across the dynamo terminals. When the solenoid plunger is drawn up, on the charging voltage rising sufficiently, it increases the resistance in the shunt-field circuit and so cuts down the output of the dynamo. From the diagram it will be seen that the resistances are so connected with the overcharge preventer and the hand switch for the lamps that the shunt-field resistances inserted by the overcharge preventer are different when the lamps are on from what they are when

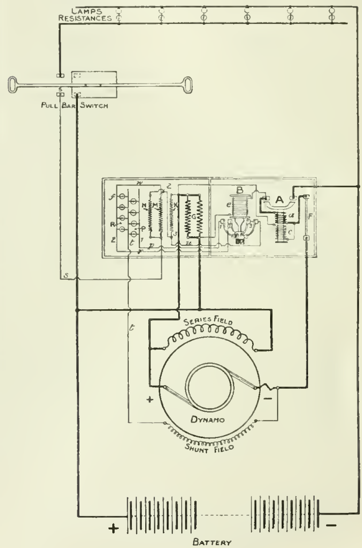


FIG. 10.

the lamps are off, as indicated in Fig. 10. It should be noted that the resistances P, R, are hot wire resistances in order to limit the shunt-field current to a given maximum.

On the Continent and elsewhere the Tudor and allied companies often use the Rosenberg dynamo instead of a plain reverse-compounded machine. The remainder of the connections, however, are similar, and this system is sometimes referred to as the Buttner system.

SILVERTOWN SYSTEM.

This system is that of the India Rubber, Gutta Percha, and Telegraph Works Company, Limited. It is an ordinary double-battery system more or less similar to the

Stone system, except that regulation is not accomplished by the slipping of the belt, but by reverse-compounding coils, which carry the charging current to the battery. A series diverter is provided to adjust the output of the dynamo in the usual way. The switches are operated by a centrifugal governor.

The systems described up to this point have been examples of constant-current working, and certainly the majority of the existing systems operate on that principle. There are, however, several systems which use more or less the constant-voltage principle of operation. The best known of these are the Brown Boveri, the Dalziel, the Grob, and the Leitner.

Brown-Boveri System.

Messrs. Brown, Boveri & Co. adapt their well-known voltage regulator for use with their train-lighting system. The main point in their arrangement is that they provide compound windings on their regulator, so that the battery charging-voltage is not held constant, but gradually rises as the battery becomes charged. By this means the battery charging-current does not have the characteristic of the purely constant-voltage system shown in Fig. 3, but more nearly approaches a constant-current

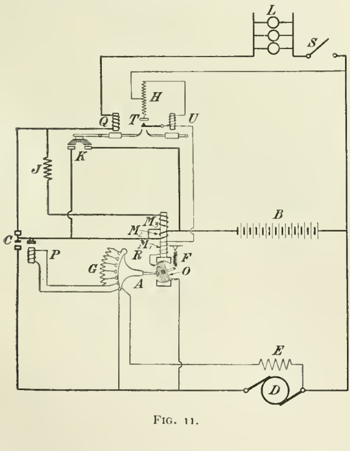


Fig. 11.

curve. A charging curve for the Brown-Boveri system is shown in Fig. 12.

The dynamo is an ordinary shunt-wound machine, the field excitation of which is controlled by the regulator. The pole-changing device in connection with the reversal of the direction of motion consists of a movable brush-rocker mounted on the end bracket and operated by a special arrangement of levers and springs. The regulator, together with the electrically-operated cut-in switches and other relays is contained under one cover. The diagram of connections for the complete system is shown in Fig. 11.

The regulator R consists of a curved track composed of silver contact studs on which the sector-shaped contactor A rolls. The various sections of the field resistance are connected to the contact studs as shown in Fig. 11. The sector-shaped contactor is rolled over the studs by means of the moving coil O, which is capable of a partial

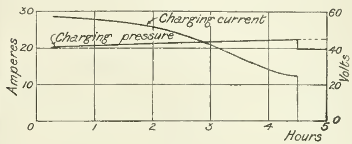


Fig. 12.

rotation between the field poles of an electromagnet with a shunt winding M_1 and series windings M_2 and M_3. The movement of the coil O is opposed by the control spring F, which has an approximately constant tension over the working range of the moving coil. The moving coil is connected in series with the fine-wire magnet winding M_1, the winding of the over-charge relay U, and the resistance H, the complete group being connected across the dynamo terminals. The winding P of the cut-in switch C is connected across the first two contact studs, so that when the dynamo is run up to normal speed and the voltage exceeds a predetermined minimum, the sector commences to roll away from its end position where it was short-circuiting the winding P. Hence, by the first movement of the sector the winding P is energized and the dynamo circuit to the battery is closed by the switch C. At the same time the direct circuit from the battery to the lamps through C is broken, and any lamp current required has now to go via series coil M_3 and lamp resistance J. If the lamps are not switched on, switch K remains open, leaving the coil M_2 active. If K were closed, the coil M_2 would be short-circuited. As the dynamo speed increases, the voltage tends to rise, but is prevented from doing so by the movement of the regulator introducing resistance G in steps into the field circuit. The current charging the battery passing through winding M_2 assists the shunt coils M_1 in moving the regulator, so that when the dynamo is running without the lamps switched on, the voltage necessary to move the regulator will be low when charging current is high, and vice versa; that is to say, as the battery charges up and its back E.M.F. increases, the current will fall, thereby in turn requiring a higher voltage of the dynamo, acting through the fine-wire windings of the regulator, to move the coil O. The battery is therefore charged on a rising voltage characteristic, which gives the charging-current curve shown in Fig. 12; this is similar to the charging-current from a constant-voltage supply main having a resistance in series. The charging will continue until the voltage builds up to the amount necessary to attract the armature of the magnet U, when the resistance H will be partially short-circuited. This

will cause the sector A to roll further over the resistance studs and the output of the dynamo to be decreased to a very few amperes.

Should, however, the lamps be switched on, current will flow through the resistance J and magnet Q; this will close the switch K and therefore short-circuit the battery winding M_2. At the same time the lamp current will flow through the winding M_3, which acts in opposition to the shunt-wire winding M_1; hence the greater the lamp current the higher must the dynamo voltage rise to balance the force of the control spring; and as the greater the lamp current the greater is the drop in the lamp resistance J, the two are proportional to each other and a steady pressure is maintained on the lamps.

In this way the lamps can be switched off and on with very little alteration in pressure; but in the author's opinion this arrangement is not good, as the larger the lamp-load the greater is the charging current of the battery, and a heavy lamp-load coming at a time when the battery is low may mean a very severe strain on the dynamo, as the compensating effect of M is absent, due to its being short-circuited by K.

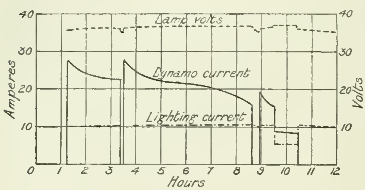


FIG. 13.

The performance curve showing the dynamo and lamp currents throughout a run lasting 12 hours is given in Fig. 13, and it will be noticed that when only half the number of lamps are in use the dynamo current is comparatively low, whereas when all the lamps are in use at the beginning of the charge the dynamo current is $2\frac{1}{2}$ times the lamp current.

This system is obviously a step in the right direction, inasmuch as it raises the voltage on the battery as charging proceeds, and is in this respect a happy compromise between the pure constant-voltage and the constant-current systems. It is unfortunate, however, that the arrangement for taking care of the varying lamp pressure should partially interfere with this good feature.

Dalziel System.

In a paper read before this Institution some years ago* Mr. Dalziel described a constant-voltage system invented by him. Unfortunately, in order to obtain the desired regulation he had to employ in addition to the dynamo a system of motor-generator and exciter gear which made the complete arrangement rather complicated, as there were too many small armatures and commutators, brushes, etc., to be readily maintained. It is interesting to learn that Mr. Dalziel has now reduced the auxiliary motor-generator system to a single exciter geared direct to the dynamo shaft. As the improved system supersedes the older one, it will only be necessary to refer to this later form.

The diagram of connections and the arrangement of the dynamo and exciter are clearly shown in Fig. 14. It will be seen that the magnetic circuit of the exciter is some-

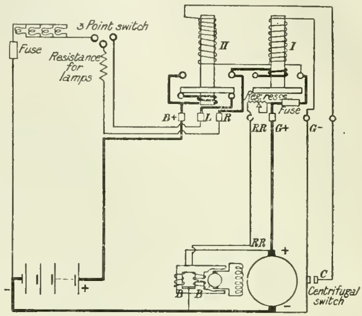


FIG. 14.

what unusual. The main generator field is connected across the armature of the exciter, which revolves in a field that is the resultant of the fluxes on the two poles B B. These poles are so wound and connected across the dynamo terminals that the magnetomotive forces produced are in series. The one pole is of small section and becomes saturated at a very low terminal pressure. The other pole is of large section, possesses a fairly long air-gap, and

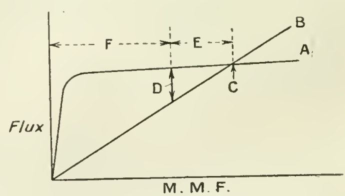


FIG. 15.

is very far from saturation, in fact, possesses nearly a straight line characteristic.

These two characteristics are shown in Fig. 15, where A is the curve for the saturated pole, and B the curve for the unsaturated pole with the air-gap. The difference between these two curves represents the flux passing through the exciter armature. Hence if D represents the difference in flux necessary to give the required excitation at the

* *Journal I.E.E.*, vol. 39, p. 156, 1907.

minimum normal or cut-in speed of the generator, the voltage cannot increase beyond the point represented by C, which is the point of "no flux" through the armature, corresponding to infinite speed; that is to say, the part E measured as a percentage of the part F is the percentage rise in the main voltage corresponding to a rise in speed from the cut-in point to infinite speed. By designing the exciter to give the necessary voltage with a sufficiently small flux, this percentage rise may be made as small as may be required. In order to keep the size of the exciter within reasonable limits, it is geared to run at a higher speed than the main generator.

The difference between the dynamo voltage and the lamp voltage is, as usual, absorbed by means of the lamp resistance. Each lamp or bank of lamps controlled by a separate switch is provided with its own resistance, and these resistances are "cut in" in one step. The dynamo is switched in parallel with the battery at the correct voltage by means of the usual solenoid switch 1, provided with series and shunt windings; but instead of switching it direct into circuit with the battery, it is switched in through the lamp resistance and the lamp switch. Assuming the latter to be closed, the path of the current is through G, switch 1, terminal R, the lamp resistance, the lamp switch, and back to terminal L, through solenoid switch 2, through the series holding coil of the same to the positive pole of the battery.

As the speed of the dynamo and its voltage increase, the dynamo takes over the lamp current, and the current in the series holding coil of solenoid 2 is reduced to zero, and this switch is free to act whenever its operating winding circuit is closed. Meanwhile this has been accomplished by means of the centrifugal switch C. The solenoid switch accordingly closes and so connects the dynamo direct to the battery, leaving the lamp resistance between the lamps and the dynamo. When the dynamo slows down, the reverse action takes place. This is where the necessity of the centrifugal switch C comes in, as it is impracticable to make solenoid 2 drop at the right moment without breaking its circuit by means of the centrifugal switch.

This system as illustrated in the diagram is a pure constant-voltage system, and the battery will be charged in accordance with the curve shown in Fig. 3. In the author's opinion, as already expressed, this is by no means the best way of treating the battery in practice, and it would be much better to insert a resistance between the positive terminal of the dynamo and terminal G and run the dynamo at a higher voltage in order to get the benefit of the diminishing drop in the resistance, with consequent building up of the voltage as the battery becomes charged. The lamps would of course be subjected to this amount of voltage variation; but as the lamp resistance would be designed accordingly, the variation on either side of the correct voltage is by no means serious.

As this system employs a separate exciter, driven from the dynamo, it does not require any further pole-changing apparatus, as the polarity of the exciter reverses when the direction of motion is changed, thus altering the direction of excitation of the main generator; which is just what is required to maintain correct polarity.

The author would like to suggest to Mr. Dalziel that instead of using a compound magnetic circuit for his exciter he could merely use a standard exciter with two shunt windings connected across the main dynamo terminals. The two windings would act against each other, but in the circuit of one he could insert a hot iron-wire resistance. This would at once limit the excitation current in that winding. The working flux would be obtained from the difference between the two excitations, and the same effect is obtained as in his compound magnetic circuit, with possibly the advantage that it is not necessary to develop a fresh machine for the purpose. It would also be possible to use permanent magnets in place of the constant-excitation winding.

Grob System.

In this system constant voltage is also used, but the dynamo runs at the same voltage as the lamps and the battery receives its charge through a booster. The booster armature and the main armature work in the same field, so that the same regulation applies to each. The Grob dynamo is arranged with its field coils in series with a regulating battery, the two being connected in series across the dynamo terminals, so that current from the battery would tend to drive the dynamo as a motor. When the dynamo, however, increases in speed it generates a counter electromotive force which gradually reduces the current and therefore the excitation; hence the dynamo voltage could never quite reach that of the battery, but from normal speed upwards it is just so much below it as is given by the varying I R drop in the coil.

A second battery connected across the dynamo and booster in series is of course required for charging. The two batteries are arranged to be interchanged at suitable intervals so as to prevent the regulating battery running down. The general idea of running the lamps direct from a dynamo, regulated to generate the lamp voltage, appears to be very good, but the complication and expense necessitated by the particular arrangement of regulation and charging is a considerable disadvantage, and the switching operations are also rather complicated.

Conclusion.

The systems described above deal with the problems of train-lighting in different ways, and the respective merits of each system are open to much discussion. A table is attached to this paper, in which is given a list of a number of systems, tabulated with reference to the various points discussed above. The constant-current and constant-voltage schemes each possess distinct merits. Judging from the examples at present on the market, it would appear that the constant-current system is by far the more popular; and most of those systems which use a constant voltage or some modification of constant voltage employ a rising characteristic for charging. Even if constant current represents the extreme of this rising voltage characteristic, yet its simplicity, ease of adjustment, independence of fine adjustment, and faculty for de-sulphating faulty batteries, commend it to the practical railway-lighting engineer, who can feel some confidence that even should the regulation of the dynamo or special regulator become somewhat coarse through unavoidable defects or rough handling, the working of the system will not be very much impaired.

In the opinion of the author single-battery systems will have to be much more universally adopted in the future if electric train lighting is to make the progress that is expected of it, as by reducing the number of cells the maintenance and depreciation costs of the equipment are certainly decreased by 25 to 30 per cent.

In conclusion, the author wishes to thank Mr. J. Dalziel of the Midland Railway, and also the following firms—Messrs. Brown, Boveri & Company, The Chloride Electrical Storage Company, The Leeds Forge Company, Messrs. Mather & Platt, The India Rubber, Gutta Percha, & Telegraph Works Company, and The Tudor Accumulator Company, for their kindness in giving him information.

Make	Single or Double-battery System	Method of transposing Batteries in Double System	Type Constant Current or Constant Voltage	Pole-changing Device	Method of Regulation	Method of adjusting Output	Type of Automatic Switchgear	Voltage Compensation in Lamp Circuit when charging	Alteration of Compensation when Lamps are switched	Alteration to Output when Main Lamp Switch is operated	Overcharge Preventer (type)
J. Stone & Co.	Double	On reversal of rotation (mechanical)	Constant current	Switch arm governor-operated	Slipping belt	Belt tension	Mechanical	Second battery	None	None	None
Leeds Forge Co.	Single	—	Constant current	Brush rocker	Cam slides armature	Spring collar adjusting nut	Electrical	Lamps across fewer cells	Self-compensating	None	Breaks field current
Mather & Platt	Double	By hand switch	Constant current	None required	Armature reaction	Field resistance	Electrical	Second battery	None	By field resistance	Adds field resistance
Vicars, Ltd. ...	Single	—	Constant current	Brush rocker	Automatic rheostat	Diverter	Electrical	Automatic rheostat	Automatic rheostat	Diverter has some effect	Switches extra shunt coil to main auto-rheostat
Tudor Co. ...	Single*	—	Constant current	Brush rocker	Counter-compounding	Diverter	Electrical	Hot iron-wire resistances	Separate hot wire resistance	By field resistance	Adds extra field resistance
Silvertown ...	Double	Mechanical	Constant current	Governor operated	Counter-compounding	Diverter	Mechanical	Second battery	None	None	None
Brown Boveri...	Single	—	Rising voltage if lamps not on	Brush rocker	Voltage regulator	Adjustment of regulator	Electrical	Fixed resistance	Regulator alters dynamo volts	Regulator alters dynamo volts	Adds resistance in regulator circuit†
Dalziel	Single	—	Constant voltage‡	None required	Differential exciter	Rheostat	Electrical and mechanical	Resistances	Each lamp or group of lamps on separate resistance	Battery charging independent	None required
Grob	Double§	Mechanical	Constant voltage	Mechanical	Series excitation armature bucking against regulating battery	—	Mechanical	Lamps on dynamo. Battery on booster	None required	Battery charging independent	None required
Buttner	Single	—	Constant current	None required	Armature reaction	Field resistance	Electrical	Hot wire resistance	Separate hot wire resistance	By field resistance	Adds extra field resistance
Newbold	Single	—	Constant current	Mechanical	Automatic rheostat	—	Electrical	Resistances	Separate resistance	By extra coil on regulator	—
Gould	Single	—	Compound	Mechanical	Carbon powder regulator. Series and shunt	—	Electrical	Separate regulator	Separate regulator	—	Shunt coil of regulator

* Requires 25 per cent. more cells on account of hot wire resistance losses
† The charge to the battery is increased when more lamps are switched on.
‡ Pure constant-voltage system
§ Has one battery as regulator.

ON A VARIABLE CONDENSER WITH A SQUARE LAW.

By W. DUDDELL, F.R.S., President.

(*Paper received 1st December, 1913.*)

Continuously variable condensers are in considerable use, especially in connection with wireless telegraphy. In using these condensers for the purpose of measurement it often happens that the quantity to be measured is proportional to the square root of the capacity of the condenser; for instance in wave-meters of the Donitz type, which consist of a fixed self-induction and a variable condenser, the condenser being set to resonance, the wave-length is approximately proportional to the square root of the capacity of the condenser.

For this reason it would be convenient in many cases if the capacity of the condenser were proportional to the square of the distance traversed by the moving part.

Rotating-sector condensers, consisting of a number of plates or sectors which move in and out between a number of fixed ones, are often used in wireless telegraph receivers. In this case the capacity, except near the extreme ends of the scale, is very nearly proportional to the angular displacement of the moving plates; in fact, in a well-constructed sector condenser if the capacity be plotted against the angle a straight line will be obtained except at the two extreme ends of the scale. This straight line does not, however, pass through the zero point. It generally passes through such a point that if a small number of degrees (say 4 or 5 in a good condenser) be added to the readings of the condenser then its capacity is strictly proportional to this quantity.

With condensers of this type used in resonating circuits it will be found that if the capacity of the condenser be chosen so as to be convenient for tuning at the lower end of its scale, then owing to the fact that the wave-length is proportional to the square root of the capacity, the longer wave-lengths at the top of the scale will be unduly separated, or if the wave-lengths are conveniently spaced at the top of the scale they are too closely crowded together at the bottom.

A number of experimenters have recognized the advantages, in certain cases, of what may be termed a square-law variable condenser; and various arrangements have been proposed and constructed to attain this result. In particular, Mr. C. Tissot* has proposed a condenser in which one set of lozenge-shaped plates (see Fig. 1) slide in and out of a corresponding set of similar-shaped plates.

It is evident that the same result can be obtained with the rotating-sector condenser provided the plates be given the correct curve. Probably a number of experimenters have already worked out the correct curve, but the author is unaware of where the results are published. The object of the present note is to put on record a curve which has been tried for the purpose, and the results obtained.

The problem is very similar to that worked out by Ayrton and Mather in the design of their electrostatic voltmeter, which is essentially a variable condenser having a definite law in order to obtain the required scale. The main difference is that in the case of the electrostatic voltmeter the rate of change of the capacity with regard to the angle determines the scale, and the zero capacity is of minor importance; whereas for the square-law condenser the actual capacity is required to be proportional to the square of the angle, and the capacity at zero position must be as small as possible.

There are a number of possible combinations of curves which give the required results. We have two sets of plates to deal with; and in what follows it will be assumed that the moving plates are fixed to a spindle and are capable of rotation through an angle of approximately 180 degrees, and that during this rotation the moving plates enter between the fixed plates. It will also be assumed that the perpendicular distance between the moving and the fixed plates is a constant, and in general small compared with the linear dimensions of the plates.

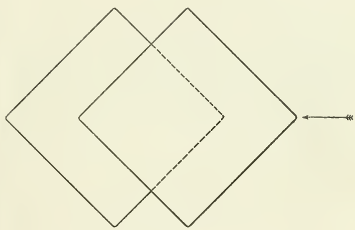


FIG. 1.

If this be the case, the capacity of the condenser is merely proportional to the area of the moving plates that are within the fixed ones, plus a small correction due to the edge effect which will be considered later. In its simplest form the problem is therefore to design the shape of the edges of the plates so that the area of the moving plate enclosed by the fixed plate is proportional to the square of the angle through which the moving plate is rotated. There are four possible simple cases:—

The inside bounding edge of the fixed plate may be a semicircle concentric with the spindle, and the outside edge of the fixed plate may be so large that the moving plate never projects beyond it, so that its shape need not be taken into account; combined with:—

(*a*) A moving plate which has its outside edge shaped to a suitable curve (see Fig. 2*a*).

(*b*) A moving plate, of which the outside edge is part of a circle concentric with the spindle and the inside edge part of a spiral curve (see Fig. 2*b*).

* *Journal de Physique*, vol. 2, p. 719, 1912.

The moving plates may have their outside edges parts of circles concentric with the spindles; combined with :—

(*a*) A fixed plate which has its inside edge constructed to a curve and the outside edge so large as not to have any effect (see Fig. 3*a*).

(*b*) A fixed plate, of which the inside edge is part of a circle and the outside edge is shaped to a curve (Fig. 3*b*).

There is no difficulty in working out curves which will approximately suit these four cases. There are also a

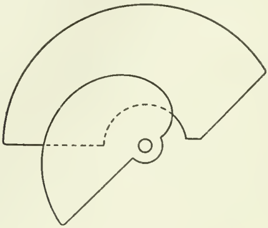


FIG. 2*a*

number of other cases where both the fixed and the moving plates have their edges cut to special curves, but there appears to be no special reason for their adoption, and they are certainly more complicated to make.

In choosing between the four types mentioned above, two considerations have guided the author to adopt the type shown in Fig. 2*a*. First, it is essential that the moving plates shall be mechanically strong; secondly,

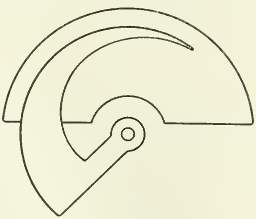


FIG. 2*b*

the capacity of the condenser when the pointer is at zero must be made as small as possible. It is usual with sector condensers, in order to make the capacity perfectly definite at low values, to line the case with conducting material and to connect the fixed plates and the interior conducting surface of the condenser together. It is therefore necessary, in order to have a low zero capacity, that the moving plates should have as little outside surface and should be kept as far away from the case as possible.

In this respect the type shown in Fig. 2*a* is good, compared with the other three types, because the latter have a considerable length of the edges of the moving plates at a distance from the spindle and therefore nearer to the lining of the case. From the mechanical point of view the type shown in Fig. 2*b* is very unsatisfactory, as it is difficult to support the moving plates from the spindle and avoid possible risk of deformation. The type illustrated in Fig. 3*a* is mechanically satisfactory, but in that shown in Fig. 3*b* there is again the difficulty of inadequate support, this time of the fixed plates.

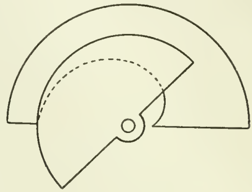


FIG. 3*a*.

The final choice has therefore to be made between the types illustrated in Figs. 2*a* and 3*a*. The curve for the edge required is practically the same in these two cases. In view of the fact that it seems easier to get a small zero capacity with the type in Fig. 2*a* than in that of Fig. 3*a*, the former was finally adopted.

The problem resolves itself into the following :—Let r (Fig. 4) be the radius of the inside edge of the fixed plates, x be one of the radii of the curve, and θ the angle through

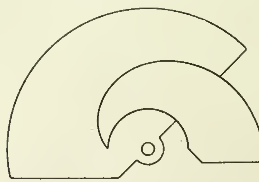


FIG. 3*b*.

which the moving plate is rotated from its zero position. The problem is to make the area $a\,b\,c$, bounded between the curve and the circle of radius r, proportional to the square of the angle θ. This leads to the following formula for the curve :—

$$x^2 = 4\,k\,\theta + r^2,$$

where k is a constant such that the area $A = k\,\theta^2$.

In the actual condenser constructed the radius r was first taken at 2 cm. and $4\,k$ at $36/\pi$, the angles being measured in radians. In this case we have the area $A = 9/\pi\,\theta^2$ and the equation to the curve is $x^2 = 36/\pi\,\theta + 4$.

Or if θ is measured in degrees, by

$$x^2 = 0{\cdot}2\,\theta + 4,$$

which is represented by the curve given in Fig. 2*a*.

The capacity of the condenser at any position θ may be easily calculated, since

$$\text{capacity in mfd.} = A/t \times 2n \times 8{\cdot}86 \times 10^{-8},$$

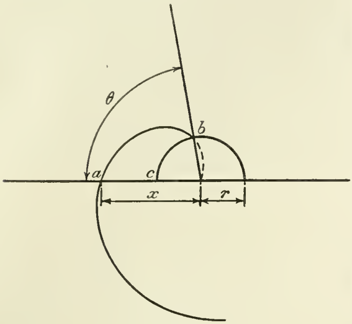


Fig. 4.

where A is the area of a plate in position θ; t is the perpendicular distance between the plates, and n the number of moving plates—always assumed to be one less than the number of fixed plates.

The condenser as made consisted of 13 moving plates and 14 fixed plates, the clearance between the moving plates and the fixed plates being approximately 1 mm. When finished, the condenser was tested and its curve plotted. It was found that the capacity was not strictly proportional to the square of the angle. A consideration of the edge effects which have so far been neglected shows that this might be expected. It also shows that an improvement can be made by increasing the radius r without altering the shape of the curve. The radius was therefore increased by 3 mm. and the condenser was re-tested.

The calibration curve of the condenser can be very closely represented by a formula of the form—

$$\text{capacity} = a + b\,\theta + c\,\theta^2,$$

in which the constants a, b, c, have the following values :—

Before increasing radius r:	After increasing radius r:
a 0·022	a 0·025
b 0·017	b 0·0035
c 0·0672	c 0·0659

where θ is measured in radians and the capacity in milli-microfarads.

It will be evident from the above figures that the increase of the radius has greatly improved the condenser and nearly made the term b negligible. Possibly a slightly greater increase would have further improved matters.

Although it has not been possible to get the initial capacity "a" as small as one would like, nevertheless the condenser has proved very convenient in use, and it is hoped that the above data may save some other experimenters from going through the work a second time.

THE THEORY OF THE THREE-PHASE SYNCHRONOUS MACHINE.

By T. F. Wall, D.Sc., M.Eng., Associate Member.

(*Paper received 31st July, 1913.*)

In a previous paper* I showed how the circle diagram for the induction motor may be deduced from a consideration of the rotating fields due to the three-phase currents in the stator and rotor windings respectively. It is here proposed to apply a similar method of treatment to the development of the circle diagram for the synchronous machine.

The circle diagram for synchronous machines has been discussed by many writers, notably by Arnold and La Cour,† who have made use of the idea of equivalent coils and the principle of inversion. In my opinion, however, the conception of equivalent coils and the principle of inversion are, for many people, too much of the nature of a mathematical abstraction, and the physical meaning is not easily grasped. I therefore hope that the method here described (which may conveniently be referred to as the rotating-field method) will allow the reader to keep in view the actual physical meaning of the steps of the development. The accuracy obtained is the same as that given by other methods. I have obtained in a simple way many of the results deduced by Arnold and La Cour from the circle diagram; and it is hoped that this may bring the circle diagram and the deductions therefrom before a larger number of readers than has hitherto been the case.

The importance of the circle diagram for the synchronous machine lies in the fact that it enables us to obtain a comprehensive survey of how the ideal machine may be expected to behave under various conditions. In practice, however, the influence of the salient poles, and of the varying degrees of saturation of the magnetic circuit, is so considerable that the results obtained from the circle diagram can only be taken as a general guide.

It is here shown how the vector diagram may be drawn and the "V" curves deduced when the saturation of the iron and the fact that the poles are salient are taken into account. The results of tests are given, and a comparison is made between the test data and the results deduced by means of the vector diagram.

* *Journal I.E.E.*, vol. 48, p. 499, 1912.

† *See* E. Arnold "Die Wechselstromtechnik," vol. 4; *also* K. Pichelmayer "Dynamobau," vol. 5.

The paper will be divided into four parts as follows:—

Part I.—The development of the circle diagram assuming that the resistance of the armature winding is negligibly small, that the field-system has non-salient poles, and that the magnetic circuit has constant permeability. The calculation of the "V" curves and the limits of stability.

Part II.—The development of the circle diagram taking into account the resistance of the armature winding, assuming that the field-system has non-salient poles and that the magnetic circuit has constant permeability. The calculation of the "V" curves and the limits of stability.

Part III.—The method of allowing for the influence of the salient poles and for the varying permeability of the magnetic circuit.

Part IV.—A comparison of the theoretical deductions with the results experimentally obtained.

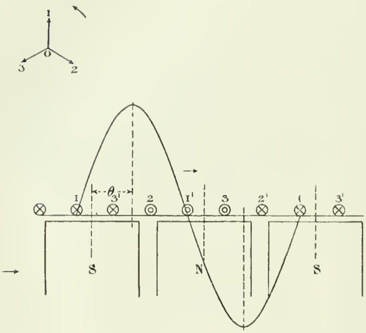


FIG. 1.

PART I.

In the paper* to which reference has been made it was shown that the vector representing the rotating field due to a current in a three-phase winding may be drawn at an angle of 90° behind the vector representing the current in any one phase. If this method of representation be adopted the vector diagram may be considered as a combined space and time diagram, because it takes into account the fact that when the current in any one phase is a maximum the rotating field cutting the conductors of that phase is zero. This is evident from Fig. 1, which represents diagrammatically a three-phase winding, and the curve shows the position of the rotating field due to the currents in the winding. This rotating field is shown in the correct relative position for the moment at which the current in phase 1 has the direction marked, and is a maximum. In Fig. 2, O A represents the vector of the current I (r.m.s. value) in phase 1, and O B the r.m.s. value of the E.M.F. induced in the conductors of phase 1 by the rotating field due to an armature current of I amperes per phase. The magnitude of the vector O B will be I . X, where X represents the total reactance of the armature winding per phase, including leakage reactance. If the pressure applied to the terminals of the armature winding be V volts per phase (r.m.s. value), and if the field-system N S in Fig. 1 (here shown, only for the sake of clearness, as having salient poles) be excited and the machine run as a synchronous motor, the poles N S will be displaced by an angle θ relatively to the rotating field that is due to the armature current, so that in Fig. 2 the vector O C will represent the E.M.F. induced in phase 1 by the revolving field-system. Since the resistance is neg-

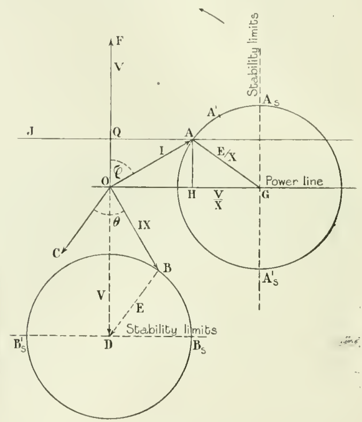


FIG. 2.

lected for the present, the two vectors O B and O C which represent the only E.M.F.'s induced in the armature winding must have a resultant O D equal and opposite to O F, the vector of applied pressure V per phase. If the excitation of the field-system N S be maintained constant and the mechanical load on the motor varied, the extremity of the vector O B must move on a circle whose centre is D and whose radius is D B equal and parallel to O C, the induced volts per phase due to the field-system. The extremity A of the vector O A must also move on a circle; and since the vector O A has a magnitude 1/X times the magnitude of the vector O B, it follows that the radius of the circle traced out by A will be E/X and the centre of this circle will be at G, where O G is $= V/X$. In Fig. 2 the circles O B and G A have the same radius, but this is of course not necessary. The circle G A is a current circle, and D B is a pressure circle. Since in this case the resistance of the armature winding

* *Journal I.E.E.*, loc. cit.; *see also Elektrotechnische Zeitschrift*, vol. 33, p. 1194, and vol. 34, p. 74, 1913.

is assumed to be negligibly small the mechanical power developed by the motor per phase will be $V\,I\cos\phi$, where ϕ is the angle between the current vector O A and the vector of the applied pressure O F. Hence the power developed by the motor will be proportional to A H, *i.e.* to the perpendicular distance of the extremity of the current vector from the abscissa axis. The abscissa axis may therefore be called the "Power Line." The machine being a synchronous machine the torque is also proportional to A H; hence the abscissa axis may be called the "Torque Line." The scale for the torque is given by—

$$\frac{\text{Volts per phase} \times \text{amperes (A H) per phase} \times 3}{746} = \frac{2\pi \times \text{r.p.m.} \times \text{Torque (lb.-ft.)}}{33{,}000}.$$

For the lower half of the circle G A the torque will be negative; and this means that the machine will then be working as a generator. When the motor is developing a torque represented by A H, and the load is suddenly increased, the field-system N S (Fig. 1) will fall back, *i.e.* the angle θ in Fig. 1 will be increased and the point A will consequently move to some position A′ until the torque developed is sufficient to overcome the increased retarding torque. Generally the point A will travel a little beyond this position of equilibrium because of the inertia of the moving parts, and it will oscillate and gradually settle down to the position for which the driving and retarding torques are equal, after the oscillations have died down. This effect, however, will not be considered further at this juncture.

The point A_s gives the position of the current vector for the maximum torque obtainable with the given exciting current. If it be attempted further to increase the load, the point A moves beyond A_s, the driving torque of the motor decreases, and the machine falls out of step. The same considerations may be applied for the lower half of the circle, that is to say, for the generator, and the point A_s' will give the maximum output as a generator. The line $A_s A_s'$ will thus mark out the limits of stability of the machine, and the corresponding points on the pressure circle will be $B_s B_s'$. For various values of the excitation a series of concentric circles will be obtained having centres at the points D and G respectively. The limits of stability will be given by the following relationship—

$$O B_s^2 = O D^2 + D B_s^2.$$

But O D is a constant, hence—

$$O B_s^2 - D B_s^2 = \text{a constant, namely } O D^2,$$

$$\therefore\ I^2 X^2 - E^2 = \text{the constant, } V^2,$$

that is—

$$I^2 - E^2/X^2 = \text{the constant, } V^2/X^2.$$

Hence if, for the limits of stability, the armature currents per phase be plotted as ordinates, and the corresponding values of the induced E.M.F.'s E as abscissæ, the curve of stability limits so obtained will be a hyperbola, the apex of which will lie on the ordinate axis, at a distance V/X from the origin.

Again, if we suppose that the excitation is so adjusted that the value of the power factor is kept equal to unity as the load varies, then the current vector will always coincide with the ordinate axis. The following relationship will therefore hold:—

$$G Q^2 = O Q^2 + G O^2,$$

that is—

$$G Q^2 - O Q^2 = G O^2,$$

or—

$$E^2/X^2 - I^2 = V^2/X^2.$$

If the values of the armature current per phase be plotted as ordinates and the corresponding values of the induced E.M.F.'s E as abscissæ, the curve so obtained for various loads on the motor at unity power factor will be a hyperbola, of which the apex will lie on the abscissa axis at a distance V from the origin. The same curves will also be obtained if the machine runs as a generator.

Let us now suppose the torque is kept constant and the excitation is varied. The current vector must then move

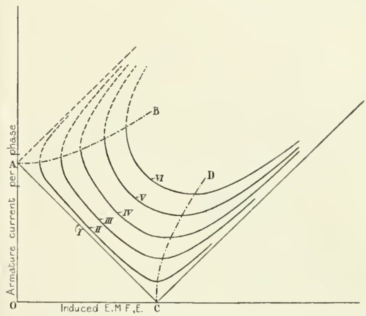


FIG. 3.

along some line such as A J in Fig. 2. If various points on the line A J be taken and the corresponding values of the armature currents per phase (*i.e.* the length of the vector O A) and of the induced E.M.F. E (equal to X times the length of G A) be plotted, a curve such as, say, III in Fig. 3 will be obtained. This is the well-known "V" curve of the synchronous machine, and it refers, as stated above, to a constant load on the motor.

In Fig. 3 a series of such "V" curves have been plotted in this way. The hyperbolas of stability (A B) and unity power factor (C D) are also shown. For the parts of the "V" curves which lie to the right of the hyperbola C D, the armature current leads on the applied pressure, and for those portions of the curves to the left of this hyperbola the armature current lags behind the applied pressure.

PART II.

The influence of the resistance of the armature winding on the circle diagram and on the power of the machine will now be considered, still assuming that the field-system

has non-salient poles. The following E.M.F.'s acting in the armature circuit must now be taken into account:—

1. The E.M.F. due to the rotating field produced by the armature current.
2. The E.M.F induced by the revolving field-system.
3. The E.M.F. necessary to overcome the armature resistance.
4. The constant applied pressure at the armature terminals.

As before, the action of one phase only will be considered. In Fig. 4, O F represents the constant applied pressure per phase. The vector O B represents the E.M.F.

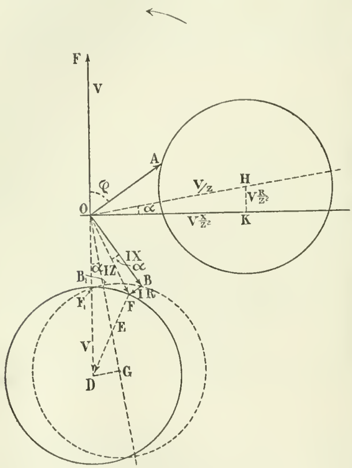


Fig. 4.

induced by the rotating field due to the armature current of I amperes per phase. The armature-current vector O A thus leads on the vector of the resulting rotating field by 90°. The vector B F represents the back E.M.F. corresponding to the armature resistance of R ohms per phase. The vector F D represents the E.M.F. per phase induced by the revolving field-system, and the vector O D is equal and opposite to O F the vector of applied pressure per phase. If the exciting current be maintained constant it follows that the extremity F of the vector D F must move on a circle of radius E, and whose centre is D. Now the shape of the triangle O B F remains constant as the armature current and excitation vary, because the angle O B F is a right angle, and the angle F O B is $\alpha = \tan^{-1} R/X$, and is of constant magnitude. Hence the extremity B of the vector O B must move on a circle whose centre lies on the line O G inclined at an angle $\alpha = \tan^{-1} R/X$ to the vector O D, and the distance of the centre G from O is O D cos α. Since the current vector O A is always at right angles to and proportional to the E.M.F. vector O B, it follows that the extremity A of the current vector O A moves on a circle whose centre H is on the line O H inclined at an angle α to the abscissa axis. The distance O H bears the same relationship to the distance O G that the length of the current O A bears to the corresponding E.M.F. vector O B, *i.e.* O H = O G/X. But O G = O D cos α, *i.e.* O G = V cos α. Therefore—

$$O\,H = \frac{V}{X}\cos\alpha = \frac{V}{X}\cdot\frac{X}{Z},$$

where—

$$Z = \sqrt{R^2 + X^2}.$$

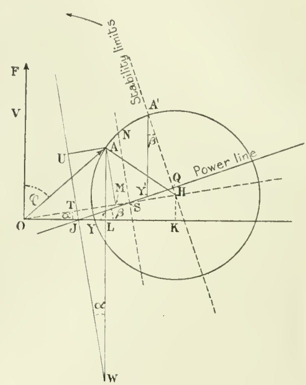


Fig 5.

The co-ordinates of the centre H of the circle H A are—

$$O\,K = O\,H\cos\alpha = \frac{V}{Z}\cdot\frac{X}{Z} = V\cdot\frac{X}{Z^2};$$

$$H\,K = O\,H\sin\alpha = \frac{V}{Z}\cdot\frac{R}{Z} = V\cdot\frac{R}{Z^2}.$$

The radius of this circle is—

$$H\,A = \frac{E\cos\alpha}{X} = \frac{E}{X}\cdot\frac{X}{Z} = \frac{E}{Z}, \quad \text{because } G\,B_1 = D\,F_1\cos\alpha.$$

It is thus evident that the effect of the resistance of the armature winding is to tilt the current circle so that its centre lies on a line inclined at an angle $\tan^{-1} R/X$ to the abscissa axis.

The power per phase of the machine corresponding to any current vector O A, is the input per phase minus the I^2R loss per phase, that is to say, it is V . A L − R . O A² (Fig. 5).

Also from Fig. 5—

$$\begin{aligned} O A^2 . R &= R[A H^2 - O H^2 + 2 O H . O A . \cos A O H], \\ &= R[A H^2 - O H^2 + 2 O H . O M], \\ &= R . O M . 2 O H + R[A H^2 - O H^2], \\ &= R . O M . 2 O H - R . O N^2, \text{ where } O N \text{ is a tangent to the circle } H N. \\ &= R . O M . 2 O H - R . O S . O H. \\ &= R . O M . 2 O H - R . 2 O T . O H, \text{ where } T \text{ bisects } O S, \\ &= 2 R . O H . M T = 2 R . O H . A U. \end{aligned}$$

But N S is the polar of the circle H A with respect to O, and T U is the half-polar of the circle H A with respect to O, that is to say, T U is drawn at right angles to O S and passing through T the point of bisection of O S. Hence the perpendicular distance of the extremity A of the current vector from the half-polar of the current circle is proportional to the I^2R loss.

Moreover—

$$I^2 R = O A^2 . R = 2 R . O H . A U = 2 R . O H . A W \sin \alpha,$$

where A W is a line drawn perpendicular to the abscissa axis.

The power input per phase $= V I \cos \phi = V . A L$.

Therefore the useful power per phase

$$\begin{aligned} &= V . A L - 2 R . O H . A W \sin \alpha, \\ &= V . A W - V . L W - 2 R . O H . A W \sin \alpha, \\ &= A W (V - 2 R . O H . \sin \alpha) - V . L W, \\ &= A Y (V - 2 R . O H . \sin \alpha) + Y W (V - 2 R . O H . \sin \alpha) - V . L W, \\ &= A Y (V - 2 R . H K) + Y W (V - 2 R . H K) - V . L W. \end{aligned}$$

If J Y is a line through J inclined at an angle β to the abscissa axis, such that

$$\frac{Y W}{L W} = \frac{V}{V - 2 R . H K},$$

then the useful power phase will be—

$$A Y (V - 2 R . H K),$$

that is to say, it is proportional to the distance of the extremity A of the current vector from a line passing through the intersection J of the half-polar J U and the abscissa axis, and inclined at an angle β to that axis, where

$$\tan \beta = \frac{Y L}{J L} = \frac{Y L}{L W . \tan \alpha} = \frac{Y W}{L W . \tan \alpha} - \frac{L W}{L W . \tan \alpha}$$

$$= \frac{Y W}{L W . \tan \alpha} - \cot \alpha = \left(\frac{Y W}{L W} - 1\right) \cot \alpha.$$

$$\therefore \tan \alpha \tan \beta = \left(\frac{Y W}{L W} - 1\right) = \left(\frac{V}{V - 2 R . H K} - 1\right)$$

$$= \frac{2 R . H K}{V - 2 R . H K} = \frac{2 R . \frac{R}{Z^2} . V}{V\left(1 - 2 R . \frac{R}{Z^2}\right)} = \frac{2 R^2}{Z^2 - 2 R^2} = \frac{2 R^2}{X^2 - R^2}$$

$$= \frac{2 (R/X)^2}{1 - (R/X)^2} = \frac{2 \tan^2 \alpha}{1 - \tan^2 \alpha},$$

$$\therefore \tan \beta = \frac{2 \tan \alpha}{1 - \tan^2 \alpha}, \text{ or } \beta = 2 \alpha.$$

Hence the angle J O T = the angle J S T, and the power line passes through S, the point of intersection of the polar S N and the line O H.

It is thus seen that the current circle can easily be drawn for any given value of the exciting current and for a given applied pressure, since the co-ordinates of the centre of this circle are $O K = V . X/Z^2$ and $K H = V . R/Z^2$, and the radius of the circle is E/Z, where E is the E.M.F. corresponding to the given value of the exciting current. The useful power is given by $(V - 2 R . V . R/Z^2)(A Y)$, where A Y is the perpendicular distance of the extremity of the current vector A from a line which passes through the intersection of the semi-polar and the abscissa axis and through the intersection of the polar and the line O H on which the centre of the circle lies.

The maximum power for any given value of the exciting current will clearly be given when the extremity A of the current vector lies on the radius H A′ which is perpendicular to the loss-line. Hence the maximum power for any given exciting current is—

$$\begin{aligned} W_{max.} &= A' Y' (V - 2 R . H K) = A' Q \sec \beta (V - 2 R . H K), \\ &= (A' H - Q H) \sec \beta (V - 2 R . H K) = (A H - S H \sin \alpha) \sec \beta (V - 2 R . H K), \\ &= \left(A H - \frac{A H^2}{O H} \sin \alpha\right) \sec \beta (V - 2 R . H K), \\ &= A H \left(1 - \frac{A H}{O H} \sin \alpha\right) \sec \beta (V - 2 R . H K), \\ &= \frac{E}{Z} \left(1 - \frac{E/Z}{V/Z} \sin \alpha\right) \sec \beta (V - 2 R . H K). \end{aligned}$$

For the maximum power which the machine is capable of giving as a motor—

$$\frac{d}{d E}(W_{max.}) = O, \quad \therefore \quad E = \frac{V}{2 \sin \alpha}.$$

$\therefore$ absolute $W_{max.}$

$$= \frac{V}{2 Z \sin \alpha} \left(1 - \frac{1}{2}\right) \left(\frac{1}{\cos^2 \alpha - \sin^2 \alpha}\right) \left(V - 2 \frac{R^2}{Z^2} V\right).$$

But $\sin \alpha = R/Z$, and $\cos \alpha = X/Z$.

$$\begin{aligned} \therefore W_{max.} &= \frac{1}{4} \frac{V}{Z} . \frac{Z}{R} . \frac{Z^2}{X^2 - R^2} . V . \frac{X^2 - R^2}{Z^2}, \\ &= \frac{1}{4} \frac{V^2}{R}. \end{aligned}$$

The point A′ on the current circle in Fig. 5 gives the limit of stability, and the limits of stability for various values of the exciting current will be given by the equation—

$$\begin{aligned} O A'^2 &= A' H^2 + O H^2 - 2 O H . A' H . \sin \alpha, \\ \therefore I^2 &= \left(\frac{E}{Z}\right)^2 + \left(\frac{V}{Z}\right)^2 - 2 \frac{V E}{Z^2} \frac{R}{Z}, \\ \therefore I^2 Z^2 &- E^2 + 2 V E . R/Z = V^2, \\ I^2 Z^2 &- (E - V R/Z)^2 = V^2 - V^2 R^2/Z^2, \\ I^2 Z^2 &- (E - V R/Z)^2 = V^2 X^2/Z^2, \\ &\frac{I^2}{1/Z^2 (V X/Z)^2} - \frac{(E - V R/Z)^2}{(V X/Z)^2} = 1. \end{aligned}$$

This is the equation of a hyperbola whose vertex is at the point $E = V R/Z$, $I = V X/Z^2$.

Further, the value of $\cos \phi$ will be unity when the extremity A of the current vector lies on the ordinate axis,

and for this condition the following equation will express the connection between E and I :

$$A H^2 = O A^2 + O H^2 - 2 O H . O A \sin \alpha,$$

or—

$$(E/Z)^2 = I^2 + (V/Z)^2 - 2 (V/Z) I (R/Z),$$
$$E^2 - I^2 Z^2 + 2 V I R = V^2,$$
$$E^2 - (I Z - V R/Z)^2 = V^2 - (V R/Z)^2,$$
$$E^2 - (I Z - V R/Z)^2 = V X^2/Z^2.$$
$$\therefore \frac{E^2}{(V X/Z)^2} - \frac{(I - V R/Z^2)^2}{(V X/Z^2)^2} = 1.$$

This is the equation of a hyperbola whose vertex is at the point $E = V X/Z$; $I = V R/Z^2$.

The "V" curves may be deduced from the circle diagram of Fig. 5, but the process is extremely laborious, since the power line J Y has a different position for each value of the induced E.M.F., E. By means of the following construction the "V" curves may be deduced with great ease.

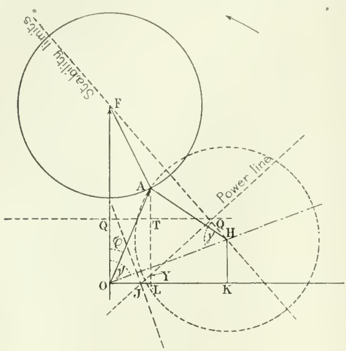


Fig. 6.

The power supplied to the motor per phase is $V I \cos \phi$ watts, where I is the value of the current per phase and $\cos \phi$ is the power factor. If R be the resistance of the armature winding per phase, the power lost in heating the copper is $I^2 R$ watts. Now suppose that the iron and friction losses are constant and represented by W_e watts per phase. Then $V I \cos \phi - I^2 R - W_e = W'$, the mechanical power developed per phase. (It will be seen later that in the more accurate vector method of deducing the "V" curves, the variation of the iron loss can easily be taken into account if it be so desired.)

We have then $V I \cos \phi - I^2 R = W' - W_e = W$, and is constant. Therefore $I^2 R = V I \cos \phi - W = V (A L - W/V)$.

In Fig. 6 mark off $T L = W/V$ and through T draw a line parallel to the abscissa axis. Then $I^2 R = V . A T$.

Now it has been shown that $O A^2$ is equal to $2 O H \times$ distance of A from the semi-polar of the circle H A with respect to the point O. Also $I^2 . R = V . A T$; that is, $O A^2 = (V/R) A T = 2 (V/2 R) A T$. But $(V/2 R) A T$ is constant ; hence the point A lies on a circle whose semi-polar with respect to O is the horizontal line through T. The centre of this circle must lie on the ordinate axis and at a distance from O equal to $V/2 R$. Such a circle is shown in Fig. 6 by F A. Since for this circle the condition $I^2 R = V I \cos \phi - W$ is fulfilled, where W is constant, it follows that for all points on circles such as F A the load on the machine is constant. The radius r of the circle F A is given by the geometrical relationship :—

$$r^2 = O F^2 - 2 O Q . O F = (V/2 R)^2 - 2 (W/V) V/2 R.$$

or—

$$r^2 = (V^2/4 R^2 - W/R) : r = \sqrt{\left(\frac{V^2}{4 R^2} - \frac{W}{R}\right)}.$$

Again, in the circle H A, Fig. 6, we have $O H = V/Z$.

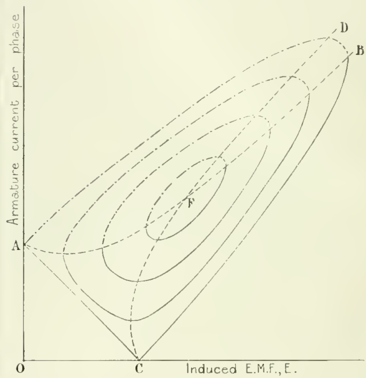


Fig. 7.

In the circle F A we have $O F = V/2 R$. The angle $F O H = 90^\circ -$ angle H O K.

$$\therefore O F \cos F O H = \frac{V}{2 R} \sin H O K = \frac{V}{2 R} \cdot \frac{R}{Z} = \frac{V}{2 Z}.$$

But $O H = \frac{V}{Z}$.

$\therefore$ F H = O F, and the angle F H O = the angle F O H.

The centre of the circle F A is thus immediately obtained by the intersection of the line H F with the ordinate axis, where the angle F H O = the angle F O H. From what has been said it can easily be shown that the line H F gives the stability limits (cf. Fig. 5).

In order to draw the "V" curves for any given mechanical load $W - W_e$, draw a circle with centre F, such that $O F = V/2 R$, and of radius $\sqrt{1/R (V^2/4 R - W)}$. Next scale off the current vectors, such as O A, and the corresponding vectors E/X, such as A H, and plot the values of E as abscissæ and the corresponding values of I as ordinates.

In Fig. 7 the "V" curves have been deduced from

Fig. 6 in this way for four different values of the load, including no load. It will be noticed that as the load increases, the "V" curves shrink until for a load W, such that $V^2/4\,R^2 = W/R$, or $W = V^2/4\,R$, the radius of the load circle F A (Fig. 6) becomes zero, and the "V" curve becomes a point (F in Fig. 7). This corresponds to the maximum possible load of the machine as a motor.

The limits of stability are given by the points at which the stability line H F cuts the constant load circles, and if these points be marked on the "V" curves they will be found to lie on the hyperbola A B. The points on the "V" curves corresponding to unity power factor are given by the intersection of the ordinate axis and the constant power circles, and if these points be marked in Fig. 7 they will be found to lie on the hyperbola C D.

Part III.

The results deduced above only refer to the case in which the field-magnet system has a continuous iron surface. When the field-system has salient poles an important modification becomes necessary. Referring to Fig. 8 let the curve represent the M.M.F. wave of the

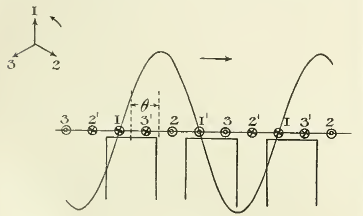


Fig. 8.

revolving field due to the armature current of I amperes per phase, and let $\bar{F}$ represent the amplitude of this wave. Also suppose that the centre of the pole of the field-system is displaced in space through θ electrical degrees, and that the field-system is unexcited. (The angle θ in Fig. 8 is the

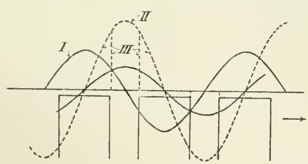


Fig. 9.

same as the angle θ in Fig. 2.) If we resolve the M.M.F. curve into two components at right angles, viz. $\bar{F}\cos\theta$ in the direction of the pole axis, and $\bar{F}\sin\theta$ at right angles to the pole axis, the former component represents the direct magnetizing (or demagnetizing) M.M.F. of the armature reaction, and the latter component the cross-magnetizing M.M.F. of the armature reaction. The flux due to the direct-magnetizing component has a circuit which has constant reluctance for nearly the whole of the M.M.F. curve, and hence the flux curve will have approximately the same shape as the corresponding M.M.F. curve. For the

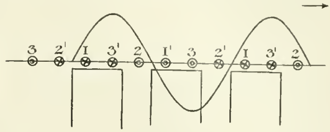


Fig. 10.

case of the cross-magnetizing component of the M.M.F., however, the reluctance of the magnetic circuit has widely different values for different points of the M.M.F. curve, and consequently the flux curve will have quite a different shape from the corresponding M.M.F. curve. In Fig. 8

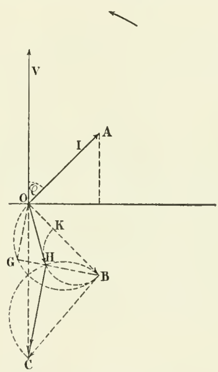


Fig. 11.

the curve shows the rotating M.M.F. wave due to the armature current when the field-system has a continuous iron surface. The curve passes through its zero value when it cuts the conductor in which the current has its maximum value. It is thus clear that there can be no torque exerted between the field produced by this resultant M.M.F. and the conductors of the armature, for they are displaced by 90° relatively to each other. In Fig. 9 curve I represents the direct-magnetizing component ($\bar{F}\cos\theta$) of the M.M.F. curve of Fig. 8, and curve I will also represent the flux due to this direct component of the M.M.F., since the reluctance of the magnetic circuit for this component is approximately constant at all points. In Fig. 9 curve II represents the cross component of the wave of Fig. 8; thus curve II of Fig. 9 has a maximum value $\bar{F}\sin\theta$,

where $\bar{F}$ is the maximum value of the curve of Fig. 8. Curve III of Fig 9 shows the flux due to the M.M.F. curve II. If curve III be analysed its first harmonic will be found to have an amplitude $\bar{F} \sin \theta \, [b/\tau - 1/\pi \sin (b/\tau) \pi]$, where b/τ is the ratio (pole breadth)/(pole pitch).* The first harmonic is shown as a full line curve in Fig. 9.

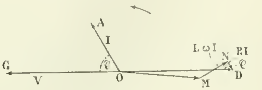


FIG. 12.

The two components $\bar{F} \cos \theta$ and $\bar{F} \sin \theta [b/\tau - 1/\pi \sin (b/\tau) \pi]$ shown in Fig. 9 may now be combined to give the actual magnetic field due to the armature currents, and if this be done the curve shown in Fig. 10 will be obtained. It should be noticed that this curve is now displaced relatively to the curve of Fig. 8, and consequently there is a torque produced between the armature conductors and

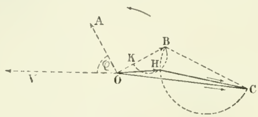


FIG. 13.

the field due to the armature current. Hence when the machine has salient poles there is a torque developed even when the field-system is unexcited, the armature current itself supplying a magnetizing component. It may even happen that a driving torque will be produced when the exciting current is reversed in direction.

In order to obtain the connection between the E.M.F., E, induced by the field-system and I, the armature current per phase, the following construction may be used :—

In Fig. 11 let the vector O A represent the armature current, I per phase, and O B the E.M.F. which would be

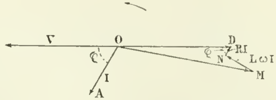


FIG. 14.

induced by the armature current I if the ratio b/τ were unity, that is, if the field-system had a continuous iron surface. If C H represent the induced E.M.F., E, we may resolve O B into a component O G parallel to C H, this component will represent the direct-magnetizing or demagnetizing effect, and is, within limits, unaffected by the salient poles. The component G B of O B which is at right angles to the component O G is reduced by the salient poles in the ratio $[b/\tau - 1/\pi \sin (b/\tau)\pi]$, where b/τ is the ratio of the pole width to the pole pitch, and thus O H will be the induced armature E.M.F. actually due to the rotating armature field. Now G lies on a circle drawn on O B as diameter, and since the ratio G H/G B is constant, H must lie on a circle whose diameter is—

$$K\,B = \frac{H\,B}{G\,B} \cdot O\,B.$$

Further, H must lie on a circle whose diameter is C B, because the angle C H B is a right angle. Hence H is

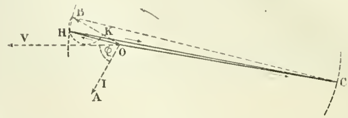


FIG. 15.

the point of intersection of circles on the diameters K B and C B respectively.

In analysing armature reaction by the Blondel or any other similar method, let i_e represent the exciting current

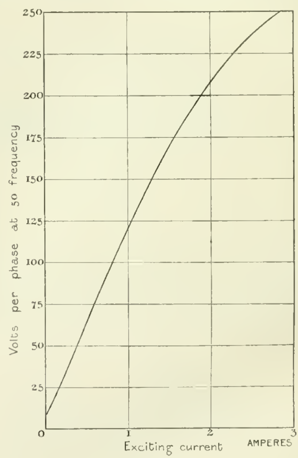


FIG. 16.

which is equivalent in its magnetic effect to a pure demagnetizing current of 1 ampere per phase. Further, let—

$L\omega$ be the leakage reactance per phase of the armature winding, so that $L\omega I$ will be the induced volts per phase due to the leakage flux for a current of I amperes per phase ;

and let R be the effective resistance per phase of the armature winding under the working conditions.

* *See* E. ARNOLD, "Die Wechselstromtechnik," vol. 4.

Referring to Fig. 12, let O A represent the current of I amperes per phase and O G the applied voltage V per phase. Then O D = O G will represent the induced back E.M.F. per phase. Draw D N parallel to O A and equal in magnitude to R I. Also draw N M perpendicular to D N and

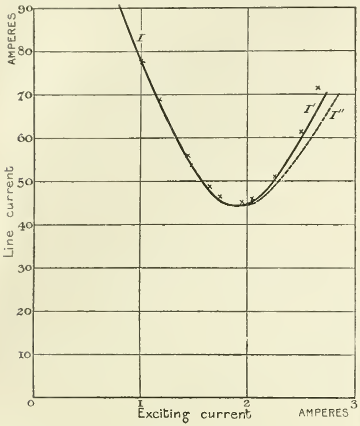


Fig. 17.

Curve II″.—Calculated values assuming the value of the leakage reactance $L\omega$ to be constant and equal to 0·97 ohm.
Curve II′.—Calculated values, the value of $L\omega$ for lagging currents being taken the same as for Curve II″, *i.e.* 0·97 ohm. The value of $L\omega$ for leading currents is taken as 0·78 ohm.
The points marked × give the experimentally determined values.

make N M equal in magnitude to $L\omega$ I the induced volts due to the leakage flux per phase. Then O M will give the magnitude and phase of the volts per phase induced by the rotating field due to the combination of the field due to the exciting current and the rotating field due to the armature current. In Fig. 13, O C is drawn in the same direction as O M in Fig. 12, and the magnitude of O C represents the exciting current necessary to induce the voltage O M per phase (Fig. 12). The exciting current O C is read off from the open-circuit characteristic of the machine.

Draw O B at right angles to O A and lagging 90° behind O A. It follows from what has been said previously that O B represents the direction of the rotating field due to the armature current.

The exciting current corresponding to an armature current of I amperes per phase is I i_e. In Fig. 13 draw O B to represent I i_e amperes to the same scale as O C is drawn. The geometrical construction shown in Fig. 11 is now made and corresponding points in Figs. 11 and 13 are, for the sake of clearness, marked with the same letters.

From O B mark off O K equal to $\bar{F} \sin\theta\,[b/\tau - 1/\pi \sin(b/\tau)\pi]$, where b/τ is the ratio of the pole width to the pole pitch. On B K and B C draw circles. If these two circles intersect at H, then H C represents the exciting current necessary when the armature current is I amperes per phase and the angle of lag is ϕ. By means of this construction the "V" curves may be calculated. For, knowing the load on the machine, assume any value of the armature current, I amperes per phase. Calculate the corresponding value of ϕ and determine by means of the above construction the corresponding value of the exciting current. In Figs. 14 and 15 the vector diagrams are shown for the case in which the current is leading.

Part IV. Comparison of the Results deduced from the Theory and those experimentally obtained.

Tests were made on a three-phase 20-kw. mesh-connected synchronous motor. By means of the Blondel test it was found that the leakage reactance $L\omega$ was 0·97 ohm per phase for a frequency of 50. The Blondel test also showed that 0·0145 ampere in the exciting circuit was equivalent to 1 ampere per phase in the armature winding. The resistance per phase of the armature winding was taken as 0·15 ohm. It is difficult to measure the effective value of the resistance of the armature winding under running con-

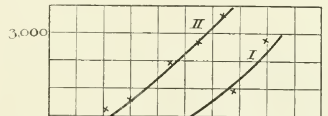


Fig. 18.

Curve I shows the power necessary to drive the synchronous motor when running light and under-excited.
Curve II shows the power necessary to drive the synchronous motor when running light and over-excited.

ditions, but from the results of some experiments the above value was considered to be approximately correct.

From the dimensions of the machine the value of $[b/\tau - 1/\pi \sin(b/\tau)\pi]$ was found to be 0·345.

The open-circuit characteristic of the machine is given in Fig. 16. The tests were made with a constant supply pressure of 200 volts between the armature terminals.

Making use of the construction shown in Figs. 12, 13, 14, and 15, and using the numerical values given, the "V" curve shown in Fig. 17 by the curve II′ was deduced. The experimentally obtained points are indicated by crosses in the same diagram (Fig. 17). It will be noticed that for lagging currents (*i.e.* for small values of the excitation) the agreement between the calculated values and the experimentally obtained values is sufficiently close, but for leading currents (*i.e.* for large values of the excitation) there is a considerable divergence. It was not easy to see how this divergence could be explained, for although one naturally suspected the saturation of the magnetic circuit to have something to do with it, the construction of Figs 12–15 has already allowed for the varying saturation of the main magnetic circuit.

A test was made with the synchronous motor running light, and the input was measured for various values of the armature currents, from a large lagging to a large leading current. The points obtained in this test are shown in Fig. 18. The fact that the input is much larger for a given value of the current when leading than for the same value of the current when lagging, showed that the iron losses were greater in the former case than in the latter, and consequently the flux density must therefore have been greater for a leading current than for a lagging current, as might have been expected from an inspection of Figs. 12–15.

This suggested that the value of the leakage reactance would also vary according to whether the current were lagging or leading. For leading currents the increased flux density in the armature teeth would cause the leakage reactance $L\omega$ to have a smaller value than that deduced from the Blondel test, in which low flux densities are dealt with. This assumption seemed to be confirmed by sending a high-frequency current through the armature winding when the machine was standing, and measuring the ratio (volts)/(amperes per phase) for different values of the exciting current.

From an examination of the results of this test the mean value of $L\omega$ was taken to be 0·78 ohm for leading currents, while the value 0·97 ohm was retained for lagging currents. By recalculating the branch of the "V" curve corresponding to leading values of the current, and using the value 0·78 ohm for this branch, the "V" curve II″ was obtained. It is to be noticed that the calculated values and the observed values now agree well throughout the whole range. It may be remarked here that if the value of the exciting current was increased beyond the largest value given for the tests in Fig. 17, viz. 2·65 amperes, the machine became unstable and easily fell out of step. This may be accounted for by the continued diminution of the value of the leakage reactance $L\omega$, due to saturation. This further diminution of the value of $L\omega$ is also sufficient to account for the divergence from the calculated curve II″ of the experimental point for an exciting current of 2·65 amperes.

The tests that have been made in connection with this paper have been many and laborious, and I wish to make acknowledgment of the service rendered by Mr. W. T. Davis in assisting with these tests.

ADDRESS TO THE STUDENTS' SECTION.

THE FOOD SUPPLY AND THE ELECTRICAL ENGINEER.

By C. V. DRYSDALE, D.Sc., Member.

(*Address delivered 26th November*, 1913.)

In giving for the second time the opening address to the Students' Section, I should like first to express my appreciation of the invitation to do so. On the previous occasion I found it necessary to deal with some matters of a somewhat controversial character, which gave rise to adverse comment in certain sections of the technical press, although my views were equally strongly supported by others. My reasons for taking this course were that, as an instructor of young electrical engineers, I felt it a matter of duty to them to look facts fairly in the face as regards their future prospects; and the reports which have reached me from time to time since have not led me to modify the opinions then expressed. On the contrary, I still feel most strongly that if young electrical engineers are to attain a success in life in any way commensurate with the training and intelligence required to qualify themselves, there must be either some great change in the industry, or they must launch out as far as possible in new directions. This evening I propose to deal specially with a recent development which is of the greatest importance to the community as a whole, and which therefore ought to offer good opportunities to the coming generation of engineers.

It is curious to observe how little the human race concerns itself with the most fundamentally important matters in connection with its own welfare. Upon what does the prosperity of a community and of its industries in general depend? Most people look at it simply from the monetary standpoint, and are quite satisfied if they manage to produce something which they can get the public to buy, whether it is of any real value or not. This policy is all right from the standpoint of the immediate self-interest of the individual, but it may be a very mistaken one from the point of view of the community, and of the individual himself in the long run. I have not a word to say against the natural desire of any student to "get on" as well as he possibly can. Quite the contrary. But although certain individuals may temporarily succeed by being "smart" business men in the modern sense of the term, I very much

doubt whether their success will endure, and it is highly probable that in the end they will seriously lose by it. The road to success (however many apparent instances there may be to the contrary) is through the ability to produce something which is really necessary for the public welfare, combined with the ability to convince the public that one has done so.

Now what is it that the human race needs most of all? The answer is simple; it needs food. Very few people realize that the prosperity of the community as a whole and of every industry is really as dependent upon agriculture as it was before the industrial era set in. There is an impression, which is fostered by writings such as those of Prince Kropotkin, that the world is capable of easily satisfying the needs of everybody; and consequently few even of the professed economists have any working explanation of the origin of industrial depression and unrest. And yet, if this idea did not blind us to the facts, we should most of us see that the food question is at the root of the whole industrial problem. Most of my audience know that this country at the present time produces only about half of the food it consumes, whether it is capable of producing it all or not. Now, where and how do we get the remainder? We get it from other countries whose industries are in a less developed state, such as Russia, Canada, and Australasia, and who send us food in exchange for our manufactures, which they need for two principal purposes—the satisfaction of their other needs, such as clothing and luxuries, and the improvement of their agriculture and means of transport, such as is provided by agricultural implements, railways, steamships, etc. So long as these other countries have an excess of food, and have not developed, or cannot develop, on the industrial side, this arrangement is of mutual advantage.

But what does this mean from the industrial standpoint? In order to produce anything, the workers have to be fed, and the wages paid to the ordinary workpeople are almost equivalent to doles of food given them while the work is being done. About 2,500,000 adult men workers in this country earn wages of 25s. a week or less, and the greater proportion of their wages has to be spent on food for themselves and their families. If we could only get out of the habit of thinking in terms of money (however useful money may be as a means of exchange) and of the idea that the total food supply is ample, we should see in an instant that the prosperity of an industry and of its workers depends almost entirely upon the total food supply and upon the share of it which the community as a whole will give to the industry as a recognition of the value of its products or services.

It follows that if the total food supply is inadequate, not only humanitarian considerations but self-interest should lead people as far as possible to undertake work which directly or indirectly leads to an increase of food and of the proportion of the total supply produced or brought into this country.

Now, is the food production of the world sufficient to feed its inhabitants? The majority of people will say yes, but they are not as a rule those who have had any experience of agriculture or who have studied the subject very fully. Prince Kropotkin is an exception; but his interesting works, which appear so convincing, are marred by a complete failure to appreciate the crux of the question, *i.e.* that the total production of food is limited by the amount of available fertilizing material, and his conclusions lose all their value in consequence.

It has long been realized by those who have studied economic or biological questions that human life, like that of the lower animals, continually presses against subsistence, and that large numbers of people in this and other countries perish annually from starvation or the diseases which undernutrition render them unable to fight against. This conclusion, which is obvious on rational biological principles, has been hotly contested, but the vital statistics of recent times strongly confirm it by showing a very close connection between the birth and death rates of different countries and of the same country at different times; and M. G. Hardy, a French statistician, has carefully compared the production of food in the civilized world with the needs of its inhabitants, and as a result finds that if the whole of the food produced were fairly distributed among men, women, and children, each would get a ration of proteids of only two-thirds of that required for full health and strength.

Sir William Crookes, now President of the Royal Society, devoted his Presidential Address to the British Association in 1898 to the wheat supply, and came to the conclusion that the world's available supply of nitrates would lead to an exhaustion by the year 1931 at the then rate of progress, a conclusion which has been endorsed this year by Professor Dixon in his Presidential Address to the Geographical Section of the Association. Sir William Crookes actually definitely predicted the rise of food prices which has been so marked lately, and that the United States, which was then a large exporter of corn, would soon cease to be so, a prophecy which has been decidedly fulfilled, as is shown by the latest publications of the Board of Agriculture.

There can be no reasonable doubt to any unprejudiced observer that there is a serious deficiency in the amount of food at present produced, and that this deficiency is likely to be more serious as time goes on. This is at the bottom of most of the difficulties of our time, of low wages, of unemployment, overcrowding, etc., and if these difficulties are to be overcome in the future, either some means must be found for increasing the production of food, or the production of human life must be considerably checked. So little do I believe that the production of food can be (or at least will be) greatly accelerated that I have felt it my duty since I had an opportunity of choice to devote my energies to the latter problem, but I shall be delighted to be proved in error, and I want to show you how you can best set about proving me wrong. If I am right, you will be both helping to increase the food supply and be making great profits, owing to your inability to keep pace with the demand. If I am wrong, and you are easily able to increase the food supply, you will do enormous service to the community by ridding it of most of the great social evils, and you will yourselves inevitably participate in the universal prosperity.

For the growth of vegetation several things are necessary, but we need only deal at present with those of which there appears to be a general or local deficiency. These are six in number: nitric acid, phosphoric acid, potash, lime, moisture, and sunshine. In many cases, as for instance in parts of India and South Africa, the rainfall is so small that it is not more than half of that necessary to produce a full crop, although the other fertilizing ingredients are probably present in ample quantity. Great

advances have been made in such regions by irrigation, and recently by what is called "dry farming," in which special methods of retaining the water in the subsoils are employed. These processes are only of interest to electrical engineers in so far as machinery is used which can be electrically operated, but electrical ploughing is coming more and more into use, and if it were adapted to the deep subsoil ploughs and other devices employed in dry farming, it might have a considerable field in places like South Africa, where power is sometimes available. A more speculative, but possibly important, electrical application might be the electrical production of rain. It is well known that in countries where the air is very pure precipitation often does not occur owing to the absence of sufficient "condensation nuclei." The erection of masts with pointed conductors charged to a high negative potential might provide sufficient free electrons (which act as condensation nuclei) to produce the required rainfall.

Turning to the question of the chemical constituents, such as nitric and phosphoric acids and potash, we are confronted immediately with a paradox which has very greatly obscured the subject. There appears to be very little doubt from recent analysis that the ordinary soil contains both nitrogen, phosphorus, and potash sufficient to supply all the requirements of ordinary crops for many years to come. An analysis of the soil in the Broadbalk field at Rothamsted (the well-known experimental farm in Hertfordshire) showed that in the top 9 inches of the soil, weighing 2,500,000 lb. per acre, there were 2,500 lb. of nitrogen, 6,750 lb. of potash, and 2,750 lb. of phosphoric acid, although the field had not been manured for 50 years. Similar or greater amounts have been found in American soils. As an ordinary crop of wheat of 30 bushels to the acre only removes 48 lb. of nitrogen, 21 lb. of phosphoric acid, and 35 lb. of potash from an acre, and the richest crop, cabbage, takes 213 lb. of nitrogen, 125 lb. of phosphoric acid, and 514 lb. of potash from an acre, it will be seen that there should be ample nourishment in unmanured soil to provide for heavy crops for 20 or 30 years.

Unfortunately these analyses appear to be totally misleading, in that the bulk of these materials are not in a state which can be dissolved by plant juices. They are of value, however, in that they indicate the possibility of processes (perhaps electrochemical ones) by which these fertilizing materials may be rendered available. So far as is at present known, they become available at a slow and nearly constant rate by the "weathering" action of sun and air, combined with the action of certain bacteria in the soil. For these bacteria to do their work, however, it is essential that the soil should be basic in its character, hence the desirability of the presence of lime. The amount of available nitric acid in the soil is increased by the rain, which brings down from 3 to 5 lb. of nitrogen to the acre at Rothamsted. It is possible also that the increased yield of crops found in Sir Oliver Lodge's electrification experiments may have been due to the production of nitric acid by the discharge from the wires stretched across the field. On the other hand the rain washes the available nitrogen out of the soil to a considerable extent, the loss having been as much as 37 lb. per acre from an unmanured fallow at Rothamsted.

It is the nitric acid which is as a rule the most deficient ingredient in ordinary soil, and it was upon the amount of available nitrates that Sir William Crookes based his remarkable prediction as to the rapid approach of the limit of the wheat supply. He did not, however, content himself with this prediction, but indicated how he thought that the serious difficulty could be solved. In 1892 Sir William Crookes had himself shown an electric wire by which the union of the nitrogen and oxygen of the air was made to take place. It is interesting to note from an address given by Mr. L. de La Vallée Poussin to the Academie de Rouen last year that the same question agitated the minds of notable Frenchmen 150 years ago. Mr. Dufourny appears to have addressed a strong manifesto to the Academy in those days, pointing out that the happiness of the human race depended on saltpetre, and asking all patriotic citizens to do their best to conserve it. At the time of the French Revolution such a declaration was signed by the members of the famous Committee of Public Safety, and five years afterwards Mr. Chaptal pointed out that the best process of producing a greater quantity of nitrates was the union of the nitrogen and oxygen of the air by means of the electric spark.

All these speculations concerning the food supply were pushed on one side, however, first by the Napoleonic Wars, and second by the great influx of food from the New World; and it is only within the last few years that the warning has again come to us that the food-producing capacity of the whole world is insufficient for its population, and that there is urgent need for fertilizing material.

The Direct Oxidation of Nitrogen.

In 1905 the Norwegian engineer, Mr. S. Eyde, commenced to apply the special form of arc devised by Professor Birkland to the commercial production of nitric acid. The latter had discovered that the essential needs for the efficient oxidation of nitrogen were a heating in the arc to 3,500° C., combined with a very rapid after-cooling to below 800° C. to prevent redissociation. To get as large a heating surface as possible he employed a high-potential alternating-current arc between long water-cooled electrodes across which a strong unidirectional magnetic field was maintained. At each reversal of the current an arc was formed, which was blown outwards by the magnetic field and travelled along the electrodes in the form of an expanding semicircle. With one direction of the current the arc was blown out on one side, and with the reverse current it was blown out on the other side. The result of the successive reversals of current, therefore, was to produce a perfect disc of concentric arcs travelling outwards like ripples on a pond, and in the latest furnaces of 400-kw. capacity each, these discs are 10 ft. in diameter.

The furnace consists of a thick hollow disc of refractory material into which the poles of a powerful electromagnet penetrate axially. The two hollow water-cooled electrodes penetrate the central chamber from the two ends of a diameter, and are supplied with alternating current at a pressure of 5,000 volts. In order to strengthen and support the furnace and to supply the air to be converted into nitric oxide a hollow iron drum surrounds the refractory disc to which air is supplied under pressure. The walls of the furnace are perforated, so that the air pene-

trates perpendicularly to the disc of flame, after which it escapes by the periphery into a pipe which conveys it to the cooling, oxidizing, and absorption towers. It first passes through a tubular boiler, thus raising steam for purposes to be described, then through a refrigerator, to the oxidation towers, which consist of long vertical iron cylinders in which the nitric oxide takes up more oxygen to form the brown nitric peroxide. Thence it passes to the nitric acid towers, which consist of granite and are filled with broken quartz over which water trickles, the nitrogen being further oxidized and dissolved to form nitric acid. The reactions are as follows :—

In the furnaces ... $N_2 + O_2 = N_2O_2$
„ oxidation towers $N_2O_2 + O_2 = N_2O_4$
„ nitric acid towers $3N_2O_4 + 2H_2O = 4HNO_3 + N_2O_2$

The nitric oxide again developed in the last process might be returned to the oxidation towers, but as it is very dilute it is found more convenient to pass it into alkali towers containing chalk or soda, which rapidly absorb the bulk of the gas to form nitrites. There is also a "hot dry absorption process" devised by Mr. Schlœsing, in which the gases issuing from the furnace and sufficiently cooled are passed direct into chambers filled with quicklime, which rapidly absorbs the oxides and forms nitrate of calcium. This is much more simple and direct than the wet process, which on the other hand has the advantage of giving a greater variety of products. From the point of view of agriculture, however, the nitrate of lime, as it is called, is very suitable, as it contains two of the constituents which are necessary to the soil.

The success of the Birkland-Eyde process has led to other attempts at attaining the same results, and those of Mr. Schönherr of Basle and of Mr. H. Pauline of Gelsenkirchen appear to have been commercially successful. The latter resembles the Birkland-Eyde furnace, except that the movement of the arc is attained by the well-known horn-break, instead of the magnetic blow-out. These horns, supported by water-cooled electrodes, are enclosed in a vertical furnace supplied from below with preheated air travelling with a velocity stated as about 1,200 ft. a second. It leaves the furnace at a temperature of about 1,000° C., and passes through the usual cooling, oxidizing, and absorption towers. With alternating current at 6,000 volts 50 ∿ a series of arcs are formed making a triangular sheet of flame, and a separate blast of cold air is directed at the tip of this flame to assist in the rapid cooling of the oxidized air.

In the Schönherr furnace, which is also employed in Norway, the arc is formed by a 4,000-volt 50-∿ supply in an iron tube 16 ft. long, through which a whirling current of air passes. The air is preheated to about 500° C. by passing through jackets round the central tube, which it afterwards enters at the bottom and ascends rapidly with a whirling motion, thus keeping the arc central. A water-cooled electrode is introduced into the tube at the bottom, and the other electrode is formed by the iron tube itself. The air, however, carries the arc to the full length of the tube, at the upper end of which there is a cold-water jacket that produces the requisite sudden cooling of the gases. The rapid development of this work is shown by the fact that in 1903 two experimental plants of 25 h.p. and 160 h.p. were started, while last year there were the following in the region of Notodden :—

Svaelgfos ...	...	40,000 h.p.	in operation
Lienfos ...	...	15,000 „	„
Rjukan ...	...	120,000* „	„
Vamma ...	...	74,000 „	„
Tyin ...	...	80,000 „	„
Total	...	289,000 h.p.	in operation

It is stated that 500,000 h.p. will probably be utilized for this purpose by the year 1916.

As regards the equipment, the principal station at Rjukan is fed from the river Maana, which has a regulated flow of 47 cubic metres per second. Ten conduits of 155-cm. diameter carry the water to the ten Pelton-type turbines, each of 15,700 b.h.p. running at 250 revs. per min. The generators are of 17,000-k.v.a. capacity, each with a power factor of 0·6 (this low power factor being due to the arcs and their necessary series inductance). Power is developed at a pressure of 10,000 volts three-phase at a frequency of 50 ∿ per second, and is transmitted about three miles by ten sets of overhead conductors partly of copper and partly of aluminium.

Apparently there is little to choose between the different types of furnace as to efficiency, and with the Birkland-Eyde process one kilowatt-year gives 500 to 550 kilograms of nitric acid, or 853 to 938 kilograms of nitrate of lime containing about 13 per cent of nitrogen. This implies a yield of 111 to 122 kilograms combined nitrogen per kilowatt-year, and as each quarter of wheat requires about 5 kilograms of fixed nitrogen, this is equivalent to about 24 quarters of wheat per kilowatt-year.

The Calcium Cyanamide Process.

We may now turn to a quite different process for the production of nitrogenous fertilizers, which is now in extensive operation, although it is less direct than the Birkland-Eyde process. In 1897 Drs. Franck and Caro discovered that barium and calcium carbide, when heated, absorbed nitrogen to form the corresponding cyanamide, the reaction in the case of calcium carbide being as follows :—

$$CaC_2 + N_2 = CaCN_2 + C.$$

They further found that when this calcium cyanamide was treated with hot water it decomposed, giving off ammonia—

$$CaCN_2 + 3H_2O = CaCO_3 + 2NH_3.$$

Both of these materials are of considerable value to the soil, and it is further claimed that the granular carbon formed in the first reaction is of great service in absorbing and destroying injurious waste products from plants. It has the advantage over nitrate of lime in being less deliquescent and possessing a higher percentage of nitrogen, but it is somewhat slower in action, as the ammonia has to be oxidized to nitric acid in the soil.

In 1906 the Alby United Carbide Factories were formed at Alby in Sweden with an extension to Odda in Norway, where a great amount of water power is available. They then erected a Linde plant for the manufacture of nitrogen, and started the process of cyanamide manufacture by an

* 107,000 h.p. additional to be employed.

associated company, the North-Western Cyanamide Company. The scheme rapidly developed, and a large number of these interests have been combined into the recently formed company, Nitrogen Products and Fertilizers, Limited, which, besides controlling this process and plants, has rights to several great sources of water power. At Odda 83,000 h.p. are already in use, and 125,000 h.p. will soon be available. There are now 20 carbide furnaces taking 1,400 kw. each, and ten 3,500 kw. each. They are almost continuously charged with powdered anthracite and burnt lime, and the molten carbide is tapped off every 45 minutes. It is then cooled, crushed, and ground to fine powder, in readiness for the conversion to cyanamide.

This process is a very simple one, the carbide being fed into vertical cylindrical furnaces or ovens having a cardboard tube down the centre and cardboard partitions at intervals, which are burnt up when the furnace is in operation, thus allowing the nitrogen gas to circulate freely among the carbide. Down the centre of the furnace is a carbon rod which is raised to incandescence by an alternating current, thus bringing the temperature of the furnace up to 800–1,000° C., at which it is kept for about 25 hours. After 35 hours the absorption of nitrogen as shown by a pressure gauge is complete, and the cyanamide is extracted in the form of black fragments, which are crushed and rolled until it forms a fine grey powder. As there is a small proportion of unconverted calcium carbide left, which would be liable to cause fire, it is treated with atomized water to dispel all acetylene, and the final product, known as nitrolim, is treated with a small proportion of petroleum to prevent further absorption of moisture. Its composition as sold is approximately as follows:—

Nitrogen, 18 %, equivalent to ammonia	21·85 %
Free lime	20 % to 30 %
Lime in combination	20 % „ 30 %
Carbon	10 % „ 12 %
Oxides of iron and alumina ...	2·5 %
Siliceous and other inert mineral substances	8 % „ 10 %

The simplicity of this process and the convenience of the product have led to its very rapid utilization. At Odda 83,000 h.p. is already used, and 125,000 h.p. will shortly be employed. The larger generators are of 12,500 kw. at 120 revs. per min., and the new ones will be of 15,000 kw. The current is generated at 12,000 volts three-phase, reduced at the carbide furnaces to 50 volts, and at the cyanamide furnaces to 60–75 volts. The nitrogen for the latter is produced by the largest Linde air liquefaction plant in the world, 100 tons of air being liquefied daily, giving off 77 tons of nitrogen (the nitrogen boiling at a lower temperature than the oxygen). The present output of the Odda factory is 80,000 tons of cyanamide annually, which is used principally as a fertilizer, but also as a basis for the manufacture of many nitrogen compounds, including explosives. The cheapest chemically-pure ammonia is produced by treating the cyanamide with superheated steam, and it is converted into nitric acid by the Oswald catalytic process.

This process has already been adopted in a number of countries, notably Italy, Switzerland, France, Germany, Japan, and the United States, the total production in 1912 being about 200,000 tons of cyanamide. Very large extensions are, however, proposed. It is interesting to note that one of the German factories obtains its power from gas engines. A plant will shortly be erected in this country to provide a certain source of nitrates for the manufacture of explosives in case of war.

In conclusion we may consider for a moment what the present and future needs of the community are as regards fertilizing material, and what has been done or is likely to be done as regards satisfying them. Up to the present it appears that the annual production of fixed nitrogen has reached 35 million lb. by the Birkland-Eyde and allied processes, and 90 million lb. by the Franck-Caro process, making 125 million lb. in all. As a quarter of wheat requires about 10 lb. of nitrogen, this output should have increased the world's output of corn by $12\frac{1}{2}$ million quarters.

The world's harvest of 1911 has been given as follows:—

Wheat	457 million quarters
Barley	174 „ „
Oats	476 „ „
Maize	466 „ „
Total ...	1,573 million quarters

Hence, even if we assume that the whole of these nitrogen products had been used in agriculture, they would have been barely equivalent to $2\frac{1}{2}$ per cent of the wheat harvest, or 1 per cent of the total harvest of cereals. It would need a supply about 50 times as great, or more, to supply even the present needs of humanity.

From physiological data it appears that the average adult man requires 20 grammes of nitrogen daily, or 7·3 kilograms annually. With the present world population of 1,700 millions, and allowing for age and sex distribution, this means an annual requirement of approximately 10,000 million kilograms. If we were to assume that the population was properly fed at the present time, and that we had only to provide for its increase, we find that in countries where little restraint on fertility takes place the birth-rate is 50 per 1,000, while where there is little poverty the death-rate is only 10 per 1,000. If therefore we are to provide for the natural increase of humanity, we must allow for a 40 per 1,000 or 4 per cent compound interest increase of population. This means a doubling each $17\frac{1}{2}$ years, or a 50-fold increase in a century.

From this it appears that if all the fixed nitrogen produced were conserved and sold in the best possible manner for food, 400 million kilograms additional would be required each year, increasing at compound interest to 800 million kilograms in 18 years, and to 40,000 million kilograms in a century. At the present yield of 120 kilograms per kilowatt-year this would require a plant of $6\frac{1}{2}$ million kilowatts, running continuously, increasing to 330 million kilowatts at the end of a century.

Of course we are not yet entirely dependent upon electrically produced fertilizers. The output of the Chili nitrate beds has increased from $1\frac{3}{4}$ million tons in 1908 to $2\frac{1}{2}$ million tons in 1912, but at this rate it appears probable that they will be exhausted within the next 20 years. Sulphate of ammonia, derived from gas manufacture, etc., is another important fertilizer, but relatively small in amount,

and everybody knows that the time has come for the economizing of coal.

There is no theoretical impossibility of producing all that is required. The fixation of nitrogen is a high-potential endothermic reaction, involving about 3,000 gramme-calories per gramme of fixed nitrogen. I have calculated that if the solar energy could be collected and utilized, the energy falling on 1·7 square kilometres, or less than a square mile, of the earth's surface would suffice for the 400 million kilograms required for the increase of the world's population, apart from the present deficit. The concentration of the sun's radiation to a focus by a large system of mirrors might possibly cause direct union of the nitrogen and oxygen of the air at its focus; but radiation calculations render this unlikely, as the theoretical limit of temperature by the Stefan-Bolzmann law works out at 3,500° C., and the actual attainable temperature would necessarily be considerably lower. There is the possibility also that suitable electrolysis of the soil might do something to liberate the large stores of fertilizing material which at present exists in an insoluble form.

On the other hand, there is the possibility of making the present available nitrogen do double duty by doubling the frequency of crops. Apart from heating the air or soil, there is the supply of artificial sunshine, or ultra-violet radiation from quartz mercury-vapour lamps, which are already coming into considerable use in cultivation under glass.

All these things show that the opportunity for the electrical engineer to affect beneficially the existence of the community is very great, both as regards producing the plant for the great developments that will undoubtedly take place in these processes, and in devising new methods of fertilizing and stimulating plant growth. Sir William Crookes indeed stated, in the Presidential Address referred to, that the electrical or chemical production of fertilizers would put an end to all anxiety respecting the food supply In this I cannot follow him.

It is 15 years since his address, 21 years since his announcement of the possibility of fixing nitrogen electrically, and over 120 years since the declaration of the *Comité de Salut Public*, and we have a deficit of at least 30 per cent in the world's food supply, and the production of fixed nitrogen has not yet affected it by 1 per cent. Observation of vital statistics leads me to the conclusion that 150,000 to 200,000 people die every year in this country as the result of under-nutrition, 2½ millions or more in Russia, 8 millions in India, and an even greater number in China. The deficit of food is not only a menace for the future, it exists and always has existed, owing to the inability of agriculture to keep pace with the growth of numbers; and in my belief the control of the output of human life is necessary, and will always be necessary, if starvation is to be avoided. But, as I said at the outset, I may be wrong, and the best way to prove it is to get these new processes into operation as quickly as possible. In the hope that some of you will be able to take your share in this great humanitarian work, and reap the benefit that will certainly accrue from it, I conclude by wishing every success to the Students' Section.

For the technical information in this address I am indebted to the Norsk Hydro-Elektrisk Kvaelstofaktieselskab and the Nitrogen Fertilizers Company. I am also much indebted to the paper read before the Royal Society of Arts on 15th May, 1912, by Mr. E. K. Scott, and reproduced in *Nature* of 4th and 11th July, 1912.

INSTITUTION ANNOUNCEMENTS.

The Faraday Society.

The Council of the Institution has been asked to bring to the notice of the members the arrangement by which members (except Students) of certain cognate societies, of which the Institution is one, may be admitted to membership of the Faraday Society without payment of the usual entrance fee of One Pound, and without the customary signatures. Full particulars can be obtained on application to the Secretary of the Faraday Society, 82 Victoria-street, London, S.W.

International Electrical Congress, San Francisco, 1915.

An International Electrical Congress will be held at San Francisco from the 13th to the 18th September, 1915, during the Panama-Pacific International Exposition. The Congress, which has been authorized by the International Electrotechnical Commission, will be held under the auspices of the American Institute of Electrical Engineers. Dr. C. P. Steinmetz has accepted the Honorary Presidency of the Congress, and the deliberations will be divided among 12 sections, which will deal exclusively with electricity and electrical practice. There will probably be about 250 papers. The first membership invitations will be issued at an early date.

Attention is drawn to the distinction between this Electrical Congress and the International Engineering Congress which will be held at San Francisco during the week immediately following the Electrical Congress. The Engineering Congress will deal with engineering in a general sense, and electrical engineering will be the subject of one of its 11 sections. It is expected that about 12 papers treating more particularly with applications of electricity in engineering work will be presented before this Section.

The International Electrotechnical Commission will meet during the week preceding the meetings of the Electrical Congress.

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SOME RAILWAY CONDITIONS GOVERNING ELECTRIFICATION.

By Roger T. Smith, Member.

(*Paper received 8th January*, 1914; *read before* The Institution *12th February, and before the* Birmingham Local Section *11th February*, 1914.)

Some of the most important and best work done by electrical engineers in this country has been expended on suburban and underground railway electrification. Yet it was not until Volume 51, published last October, that any important contribution on the subject was made to the *Journal* of this Institution. That volume contains a paper by Mr. Lydall on electric locomotives—to be referred to later—and the papers on electric traction which formed the larger portion of the subjects discussed at the Paris meeting of the Institution last May when we were the guests of La Société Internationale des Électriciens.

Circumstances have decreed that up to the present time British electrical engineers have to go to the Continent or to America for examples of railway electrification for other than urban or suburban services. Now that the Institution proposes to have a series of papers on the subject of railway electrification it seems desirable to deal in the first of them with some of the railway conditions in this country which may account for our apparent lack of enterprise. Each country has its own railway conditions and economics, and because main-line electrification is economically sound or experimentally desirable in parts of Europe and the United States it does not follow that it may be equally right for us. The dearness of money and the demands of labour make it at the present time very difficult, if not impossible, for British railways to spend money in experiments on electrification other than on a small scale.

In a country like ours, possessed of a system of steam railways which have cost more to build than railways elsewhere, a third generation of men inheriting the traditions of the past is being trained to work them. It seems reasonable that if any change from steam to electricity is proposed by electrical engineers they should first endeavour to provide something which will at least do what steam will do, next try to give electrically what steam cannot give, and finally do this in such a way as will result in improved financial prosperity to the railway. It is far easier to change things than to change the habits and inherited instincts of large bodies of men, and electrical engineers have not only to show railway managers that they can haul the railway traffic either better or more cheaply than is done to-day by steam, but that they can first of all haul traffic at least as well as it is hauled by steam, and fulfil most if not all of the functions of the steam locomotive in the manner in which those who work the traffic have been accustomed. Any proposal, otherwise economically correct, that will suddenly alter the way in which large bodies of men have been accustomed to handle traffic in the past is not sound engineering or sound business unless the resulting gain is very considerable.

At the Paris meeting the Institution had the advantage of discussing not only certain applications of electric traction to French railways, but also a reasoned analysis on the position of electric traction on the railways of the United States as it appeared to a French engineer.*

As an outcome of that discussion, and with the view of suggesting some of the things in railway working which steam now does, and are already done or will have to be done as well or better by electricity, it is convenient to divide railway services into three groups. These three groups correspond to entirely different conditions as far as traction is concerned.

1. Urban and suburban passenger services.
2. Fast passenger services.
3. Fast or slow goods and mineral service.

It is not pretended that this exhausts the types of services for which it is profitable to consider electric as compared with steam haulage. For instance, the electrification of terminals is not included, nor incline working, nor the marshalling of passenger and goods trains, nor the working of goods and mineral shunting yards. Shunting conditions only will be referred to later. The above division is sufficient, however, for the purpose of such generalization as is alone attempted in this paper.

* H. Parodi. "Railway Electrification Problems in the United States." *Journal I.E.E.*, vol. 51, p. 526, 1913.

1. Urban and Suburban Passenger Service.

Urban passenger service.—A purely urban electric service is a thing so much apart, and has been so excellently engineered as far as London is concerned in its underground railways, that it is not necessary to discuss it in any detail here, since it differs only in degree from suburban service. Steam traction for underground services is out of the question in the twentieth century, quite apart from any special advantages that electric traction may possess over steam traction in the matter of services with frequent stops averaging about half a mile apart. All underground passenger haulage must be electric.

Suburban passenger service.—A suburban passenger service exists to enable a working and business population to live outside the town in which it works. In this country suburban transport has mostly grown haphazard with the population and its extent is governed by the time which people consent to spend in the train between their homes and their business occupation. Excluding outer suburban service the limit may be taken to be about 45 minutes each way. The greater the distance covered in that time, that is to say the higher the schedule speed (average speed including stops) of the train the more chance has the railway of creating new traffic.

If a railway possessing a suburban system equipped with permanent way, platform accommodation, and locomotives designed for a certain time-table finds this equipment outgrown by the traffic, it is obvious that it must increase the number of coaches run in a given time. To do this several courses are open.

First, it may double or treble the number of tracks and increase both the number and length of its platforms, thus increasing the number of passengers carried without necessarily increasing the journey schedule time. In the past this has been done on several of the London railways with suburban services, the cost of widening the line and rebuilding the stations having been enormous.

Secondly, the railway may retain its permanent way and stations and with them the maximum length of its trains, but increase their schedule speed by using the biggest type of steam locomotive permitted by the load gauge for running comparatively light suburban trains. This has been worked out and tried experimentally for the Berlin suburban service,* but comparatively little has been done by locomotive engineers in this country to design a steam locomotive purely from the point of view of the rapid acceleration of a light suburban train. It has been done on the Great Western Railway and also in the case of the rail steam auto-car, which, with high adhesive weight, does possess fairly rapid acceleration.

Thirdly, the railway may electrify, which solution is commending itself to many of the railways in this country with congested suburban services. With electrification a maximum of 48 trains an hour can if required be run each way during the rush hours while employing existing stations and tracks. That it is possible to run trains so close to each other is chiefly due to signalling by track circuits, but full advantage of the possibilities of running up to 40 or more trains per hour by the use of track-circuit signalling can only be taken by trains having rapid acceleration and very rapid deceleration. With tracks and stations (and hence also the train length) remaining as before, the number of passengers carried per hour has in many cases been doubled by increasing the schedule speed 50 per cent, while improved signalling has at the same time made it possible to increase by 50 per cent the maximum number of trains per hour.

The characteristics of urban and suburban services for which electric traction is suitable are a dense or fairly dense service of not less than, say, 5 trains per hour each way, up to 40 and more per hour each way, with station stops varying from less than half a mile apart up to $1\frac{1}{2}$ miles apart. With services less dense than the minimum, and with stops further apart on the average than the maximum here given, the advantages of electric traction, if they exist, are special and not characteristic.

The essential element which gives to electric traction its advantage over steam under these conditions is the motor-coach train. The train is made up either entirely of motor coaches (as in the western suburban system of the French State Railways) or of motor coaches and trailers. The number of motor coaches must be such that the weight on the driving wheels available for adhesion is not less than 25 per cent of the total train weight. It is more often 33 per cent, and may be 100 per cent. The making up and driving of such trains have been rendered possible by multiple-unit control.

With the motor-coach train it is quite easy to have such an adhesive weight as will permit of a tractive effort, over and above that required to haul the train against resistances, sufficient to accelerate it during the notching period at rates up to $1\frac{1}{2}$ miles per hour per second (2·2 ft. per second per second), while the rate of deceleration is usually increased up to 2 miles per hour per second. Such a rate of acceleration is not often justified, and a more characteristic example may be taken from one of the London suburban services where trains weighing 175 tons are accelerated during the notching period at 1·7 ft. per second per second to give with 20-second stops a schedule speed of 17 miles per hour, the station stops averaging half a mile apart. The adhesive weight is 46 per cent of the train weight, and the energy input while accelerating is 1,300 h.p. Within the load gauge of this railway no steam locomotive could be built of such a power. If it could be built it would have (in order to give the necessary adhesion and power) four times the weight of the electrical equipment, which is distributed over 8 axles.

Although belonging more to the economic than the engineering side now under consideration, the cost in energy of such a reasonable acceleration and schedule speed, which is about that of most of the London underground railways, is shown by Fig. 1, representing actual tests of 20 such trains, the rate of acceleration being constant at 1·7 ft. per second per second while the distance between stops varied, giving an average schedule speed over the whole distance of 17 miles per hour. The energy in watt-hours per ton-mile at the train includes the moving and controlling of the train only; brake pumping, lighting, heating, and idle mileage being excluded.

Other advantages of the multiple-unit-controlled motor-coach train, as has often been stated, are first the doubling of terminal accommodation by halving the number of

* Trials have been made on the City and North Circular section of the North Circular Railway of the Berlin City Circular and Suburban Railways with a 2—6—0 and 2—8—2 tank steam locomotive hauling 300-ton trains.

signal and locomotive movements, and secondly the ability to make and break up the motor-car and trailer units of which the maximum train is composed to suit the traffic.

No piece of apparatus is more fitted to accelerate a train rapidly than an electric motor with a series characteristic. The series-parallel connection of the continuous-current motor can give without opening the circuit two running speeds for each definite load after acceleration is complete, while in the single-phase motor voltage regulation can give as many running speeds as are desired.

For any suburban service requiring 20 trains per hour to bring morning passengers in and take evening passengers

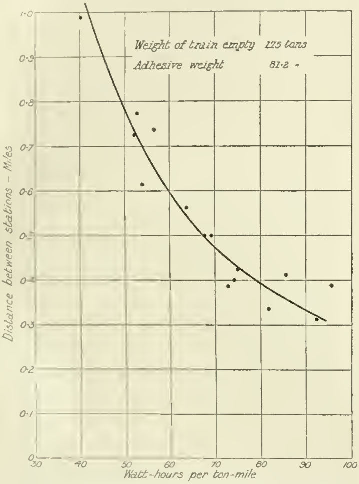


FIG. 1.—Curve of energy consumption for London Suburban Motor-coach Train plotted with distance between stops for a schedule speed of 17 miles per hour. 20-second stops at stations.

out of a city, tracks and terminal accommodation must be set apart exclusively for the purpose. It is not overlooked that two of the most important and successful suburban electric services in this country, namely, the Liverpool suburban services of the Lancashire and Yorkshire Railway and the Newcastle suburban service (if such it may be called) of the North-Eastern Railway, run for some distance over main lines used by steam trains. The maximum number of trains per hour is 12 each way in the case of the Lancashire and Yorkshire service, and 6 each way in the case of the North-Eastern service. The North-Eastern electrification is something more than a suburban system, while the Liverpool-Southport service is a very successful experiment in the creation of new traffic, which makes it typical of the best sort of suburban service.

In general, however, it is safe to say that until it is necessary to devote terminal facilities, station accommodation, and at least two tracks entirely to a suburban service, it is very doubtful if electrification is the only solution of the congested traffic problem, although it may prove to be the best solution. Most of the suburban services into and out of London already electrified or in process of being electrified are run on tracks distinct from the main line, and such a service becomes a thing apart. It can be electrified on any system which best suits its conditions, and the method may be quite different from any other method which may subsequently be desired for main-line electrification.

Under such conditions—and they are exemplified on the largest scale in Europe by the suburban lines leaving the St. Lazare Paris terminus of the Western French State Railway system—the results of suburban electrification all the world over show that there are really no fresh engineering problems to be solved. On both sides of the Atlantic there are numerous examples all more or less on the same lines, two new systems out of London, one north and the other south of the Thames, being now in process of equipment by the London and North-Western Railway and the London and South-Western Railway respectively. Compared with steam haulage the measurements of power are so simple and cheap that when the traffic department asks for any reasonable schedule the engineer is not only able to design his equipment to work to it, but can say within very close limits what it will cost in power and what it will cost in maintenance.

Passing from the engineering to the economic side, the question of the electrification of a suburban system has become for a railway company purely one of finance. Essentially it resolves itself into a question as to whether the fares charged for the service, even with the additional traffic obtained, can give a reasonable return, or any return at all, upon the new and old capital, after the cost of working has been provided for.

When electric tramways were developed in this country for urban and suburban services they competed directly with railway steam services in many large towns. As an example, when London started its electric tramway service on the south side of the river the suburban steam service of the Brighton Railway decreased from 8 million passengers to 5 million passengers per annum. On electrifying its lines not only did the railway regain this loss in the first year, but it has since added to its traffic steadily; at fares, however, lowered by the tramway competition.

It must be remembered that the tramway uses the streets and pays only for its construction, for part of the paving, and for a part or the whole of necessary street widenings. The railway has paid for the land—often acquired compulsorily at an exorbitant price—and has had to put on the land costly permanent way and structures. Usually a railway company is the largest ratepayer in any parish through which it passes, and is often the largest ratepayer in any town. It may therefore be called upon to pay rates to a municipal body on which it is not represented, in order to keep up part of the roads used by a competing tramway. If the municipal tramway is run at a loss the railway helps to pay the losses of a competitor whose presence reduces the railway fares.

The tramway in turn is now menaced by the competition

of the motor omnibus, which pays nothing beyond the petrol tax for its right to use the roads in order to compete with both railway and tramway.

The management of a railway has to decide in each individual case whether, considering its handicap in the cost of its road, which one of its competitors has not to meet at all, and its high rating, which may go to assist the other competitor, it can make enough money out of competitive fares to justify the added cost of electrification.

Even when it cannot make the development of its suburban traffic pay directly it may still pay the railway as a whole considered only as a feeder to the main line, or urban and suburban traffic as a whole may pay if the latter goes far enough out into the country. This latter type of suburban service is best illustrated by the Liverpool-Southport electrified system on the Lancashire and Yorkshire Railway.

From Liverpool to Hall-road, $7\frac{1}{8}$ miles away, the average distance between stops is $\frac{7}{8}$ mile and the schedule speed is above 25 miles per hour. This is probably the most rapid suburban service in existence. From Liverpool to Southport is $18\frac{1}{2}$ miles, with an average distance between stops of $1\frac{1}{3}$ miles, but beyond Hall-road this average is only a little under 2 miles. The schedule speed of stopping trains is 30 miles per hour. The maximum instantaneous input to the train is nearly 2,000 h.p., and the power consumption for the stopping trains to Hall-road is about three times the power averaged over the whole service of stopping and express trains and idle mileage. This is an excellent example of how a service if extended far enough out and combining express with stopping trains reduces the energy used over the whole system to a reasonable figure. The long-distance fares have to make up for the far greater cost of the short-distance stopping service.

Not only have electrical engineers completely solved the engineering problem of frequent service with short distances between stops, but the cheap and simple measurements of electrical quantities have taught railway companies for the first time how costly the constant stopping and starting of a train must be as compared with running at high speeds with infrequent stops, whatever form of power is used for traction.

It is not that suburban electric traction costs an unreasonable amount, but that circumstances make the revenue from such services unremunerative. Suburban fares have been falling steadily, and at the present moment it is safe to say that everybody in London and its suburbs is being carried at too low a fare to give proper remuneration to any form of traction which, in addition to rates and taxes and government duty on some fares, pays for its road and the right to use it.

From the report of the London Traffic Branch of the Board of Trade for 1912, particulars of London urban and suburban traffic can be obtained and compared with the returns and estimates of the omnibus and tramway traffic. From these returns it appears that if the suburban systems of the main-line railways running into London are left out of account there has on the whole been no increase during the last three years in the number of passengers carried by the underground railways of London, all of which are electric. Quite considerable increases have taken place in some lines—the District carried $7\frac{1}{4}$ per cent more passengers in 1912 than in the previous year—but other lines lost some of their passenger traffic, and the total number remains stationary at about 436,000,000 passengers per annum. The average fare was a trifle above $1\frac{1}{2}$d. The purely London traffic of the main-line railways—inclusive of their suburban traffic—is estimated for 1912 as 250,000,000, which is a decrease of $1\frac{3}{4}$ per cent on the traffic of the previous year.

The London tramway traffic in 1912 is estimated at 800,000,000, which is a decrease of 3 per cent on that of the previous year, while the omnibus traffic amounted to 550,000,000, or an increase of 37 per cent on the 1911 figures. Greater London traffic as a whole increased by 125,000,000 passengers in the same period, which is 20 per cent less than the omnibus increase, every other form of traffic having declined except that on the underground railways, which remained stationary.

A Parliamentary Committee has been investigating the problem of the city, circular, and suburban services in Berlin, and it reported at the end of 1912. Fares have been reduced to such an extent that in that year they averaged $\frac{3}{4}$d. per passenger, or half the average unremunerative fare in London. With steam traction these fares do not pay working expenses, and no capital charges whatever have been paid of late years on about £12,000,000 spent on the Berlin railways.

In 1913 money was voted for the electrification of the city and circular railways, but the suburban electrification is not to be dealt with at present. The point of interest is that, after electrification, fares all round are going to be raised to such a figure as will not only pay working expenses but capital charges (interest and amortization) on the old and new capital.

Like most other industrial working costs, that of running a suburban service depends on certain standing charges which taken as a whole do not vary, or hardly vary, with the service given (upkeep of permanent-way equipment, management, rent, rates and taxes, and station traffic expenses) and a charge varying with the service catered for (rolling-stock repairs and wages, running wages and electricity). In a particular case the ratio of standing to variable charges for running a small suburban service for a year was as follows: Standing charges unaffected by the number of trains 60 per cent, variable charges 40 per cent, and of this 40 per cent electricity formed three-fourths.

If the cost of electricity can be reduced by 50 per cent the total working costs may be reduced by one-quarter, which shows the importance of cheap electricity. This is a particular case where the cost of electricity was high, and as a rule its percentage effect is not so great.

Fig. 1 shows how, for a given average schedule speed, the distance between stops affects the amount of electricity used, and supposing it were possible to have a differential tariff for railway passengers based on the actual cost of the service, the short-distance passenger ought to pay much more per mile than the long-distance passenger, since he costs more to carry; but on nearly all suburban services competition has cut down the fares of the short-distance passenger to a non-profitable point.

What is wanted to make urban traffic on electrical lines pay is either an increase in the fares, which is achieved abroad by zone fares, or the ability to purchase electrical energy delivered to the conductors at say $\frac{1}{4}$d. per

kilowatt-hour. Competition may prevent the former. Is there any chance of obtaining cheaper electricity?

The generation of electrical energy and its supply is a business in itself. In many cases it has not in the past been possible for railways electrifying suburban services to buy electricity from outside,* but wherever they have been able to do so the saving of the initial cost on which capital charges have to be met and the saving to the railway of the management of a business organization that is very different from its other organizations are a great gain. In general the addition of a load which in the case of a heavy suburban service may continue during 18 or 20 hours out of the 24 with an annual maximum demand load factor of from 45 to 55 per cent, should enable a supply authority with a light and power load to offer a railway company such a price as would leave no question as to its acceptance. It is scarcely necessary to point out, however, that the purchase of electrical energy has not been the policy of the majority of the railway companies. Some of them have had no chance of buying, but those like the North-Eastern and London, Brighton and South Coast Railways who have purchased electrical energy have no reason to regret it.

To sum up the situation with regard to suburban electrification as it appears to the author, the electrical engineer is in a position to inform his railway very exactly what the initial and working cost will be. The management have to decide what the financial result will be with the existing and expected traffic, which has to pay working and capital charges on the new capital before earning a dividend on the old. Competitive fares are so low that the process is generally discouraging except where a new traffic can be created in districts from 10 to 30 miles from the terminus. The cost of electric working is important, but as Mr. Insull has recently pointed out the cost of money may be still more important, and the raising of fresh capital for anything that is not certain to swell the dividend is a very serious matter indeed at the present time when the credit of British railways stands so low.

2. Fast Passenger Service.

When the condition of frequent stops and short distances between them is left and the question of main-line passenger services as run by steam locomotives is considered from the point of view of electric traction, the problem alters completely.

To give some idea of the effect of stops it may be mentioned that in a particular steam service a 7-coach train weighing 187 tons, including a dynamometer car, required an average draw-bar horse-power of 277 when hauled by a steam locomotive at an average schedule speed, including stops, of 40 miles per hour, the stops on a nearly level road being 23½ miles apart. The same train, run at an average schedule speed of 27 miles per hour and stopping on the average every 5½ miles, required an average draw-bar horse-power of 284, or practically the same. The time taken to do the same distance is in the ratio of 1 to 1½, so that the energy used for the stopping service for the same distance is 50 per cent greater than for the fast service. The condition of the track, wind, and weather make such great differences in the power, that any generalization from individual tests is dangerous, and such tests are too costly to be made often; but such an instance will serve to indicate how increasing fourfold the number of stops in a given distance makes the cost of hauling a slow train much greater than the cost of a moderately fast service with few stops.

A good deal of experimental and pioneer work has been done on the Continent and in the United States in electric locomotive design, but the engineering problems which have to be solved in this country before fast passenger electric services can compete with existing services have hardly been considered.

In a paper such as this, only intended as a preface to more detailed papers and to stimulate discussion, it is

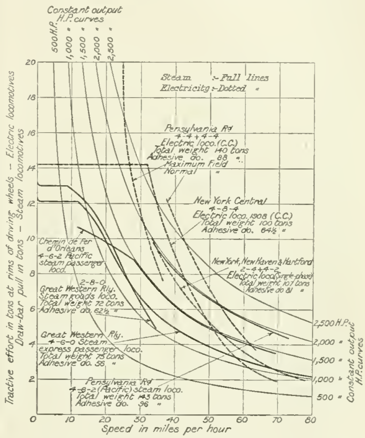


Fig. 2.—Curves of maximum continuous draw-bar pull (steam locomotive) and maximum tractive effort at driving-wheel rims (electric locomotive) plotted against speed.

impossible to do more than touch in general terms on some of the difficulties; but those interested are referred to two papers* read before the American Institute of Electrical Engineers last May, where a very useful method of analysis is developed and many constants given for comparison between steam and electric working. The discussion is, it must be remembered, purely on American practice where traffic conditions are entirely different from those in this country, but the principles of the analyses are the same for all countries.

The chief difficulty in the way of electrification for fast passenger services is the existence of the steam locomotive. Fig. 2 gives curves kindly supplied to me by Mr. G. J.

* See Chairman's address to the Newcastle Local Section, *Journal I.E.E.*, vol. 52, p. 17, 1914.

* H. M. Hobart. "2,400-volt Railway Electrification." *Proceedings of the American Institute of Electrical Engineers*, vol. 32, p. 1015, 1913.

C. P. Kahler. "Trunk Line Electrification." Ibid., vol. 32, p. 1057, 1913.

Churchward, of draw-bar pull plotted against the speed for two types of steam locomotives, one for passenger service (the 4—6—0 type*) and one for goods service (the 2—8—0 type). The curves represent the average results for saturated steam of many experiments with each type of locomotive hauling actual trains, the draw-bar pull being measured by the dynamometer car. The two types of locomotives may be taken as representative, one for hauling fast passenger trains and the other for hauling fast goods trains with nearly the maximum loading on the coupled axles permissible for British way and structures. They also represent approximately the maximum powers which can be developed by steam locomotives built within British load gauges, which are not the same for all our railways. Constant-output draw-bar horse-power curves are added for guidance. Curves of an American and of a French steam locomotive of the 4—6—2 or Pacific type are added for comparison.

The steam locomotive is so designed that with earlier and earlier cut-off as the speed increases, practically constant outputs are obtained for the same load. The time-tables of British railways imply maximum speeds of between 70 and 80 miles per hour. The resistances to train movement increase in proportion to the speed raised to the $\frac{5}{3}$ power, so that for trains running with infrequent stops a locomotive with constant output has sufficient reserve of power at low speeds, over and above that required to overcome resistances, to give a moderate acceleration (up to the limit imposed by the adhesion of the coupled wheels) and to maintain the train at any speed (determined by the regulator and the cut-off) up to the maximum speed with that load.

To all interested in this problem Professor Dalby's paper† on dynamical diagrams of the motion of a train is recommended.

As compared with the electric locomotive the steam locomotive is handicapped by the distribution of weight due to the length of the boiler. In the former, from the shape and size of the motors it is possible to get a greater ratio of adhesive to total weight than in the latter, especially if every axle is driven. In general for fast passenger service the acceleration of the steam locomotive is limited not only by the boiler capacity but by the maximum adhesive weight on the coupled driving wheels.

For the 4—6—0 type locomotive, the adhesive weight being absolutely limited by structures to 60 tons, and by usual practice to 56 tons, the starting draw-bar effort is limited to about 16 tons. From the start until the driving wheels are moving at about 50 revs. per minute—say about 12 miles per hour for the engine under discussion—the maximum draw-bar pull is 12 tons, determined by the adhesion.

Such a passenger engine can haul a train of 450 tons on the level at the highest speeds called for in this country and, unassisted, a train of 300 tons up a gradient of 1 in 50. The maximum length of the train is in general limited by the minimum length of the station platforms, and without radical changes in station structures no heavier trains can be run except for occasional "rush" traffic. To haul such a train, a constant-output locomotive is satisfactory, and the control of the output and speed by the regulator and the cut-off is so complete that the steam locomotive can run at any speed below its upper limit for the load hauled.

With the exception of certain three-phase locomotives in Italy and America, all the electric locomotives built have been equipped with motors having series characteristics. At any given voltage the series motor has one speed for each definite load. Series-parallel control with continuous-current motors gives two speeds, and with certain numbers of motors three speeds for continuous working can be obtained.

The problem of getting the adhesion necessary to prevent the slipping of the wheels when starting is, in general, possible with appreciably lower axle loads than for the steam locomotive, while for the same tractive effort the advantage in total weight is always in favour of the electric locomotive. Since the series motor can be overloaded momentarily 75 per cent above its hourly rated capacity, while for adhesion purposes if necessary every axle can be made a driving axle, even greater starting torques than those shown in Fig. 2 are possible, but on British railways they would be not only useless but actually harmful, exceeding the draw-gear strength. Unlike the case of the multiple-unit train, the adhesive weight may be only 12 or 14 per cent of the total train weight, and the strength of the draw-gear limits the draw-bar pull after starting to 12 tons. But with an increase in speed the torque of the series motor falls off so rapidly that above 60 miles per hour (where difficulties begin with steam locomotive design) no electric locomotive yet built for hauling only such maximum loads as obtain on our railways could give anything like 1,100 h.p. at 70 miles per hour, as given by the 4—6—0 steam locomotive shown in Fig. 2.

Fig. 2 shows tractive effort curves of a few fairly modern American electric locomotives, the loads representing not draw-bar pull but tractive effort at the rims of the driving wheels, so that the hauling of the locomotive itself is included. They are added to show how very quickly the tractive effort at the rims of the wheels falls off at high speeds. Such locomotives are only of academic interest to us, as their starting effort is quite beyond the strength of draw-gear on British railway passenger stock.

Very valuable information on the performance of modern electric locomotives is given in Mr. Lydall's paper communicated to this Institution,* both in the table of particulars and in the text, but it will be noted that with the exception of the two locomotives of the 4—4—2 type (Mr. Lydall's 2—B—1) and the 2—6—2 type (Mr. Lydall's 1—C—1) with maximum tractive efforts less than half that of a 4—6—0 steam locomotive none are intended to run at speeds of 70 miles per hour or over, which is required for fast passenger service in this country.

Mr. Lydall, on p. 747, lays down the requirements for a fast passenger locomotive capable of giving a draw-bar pull of 10 tons at 40 miles per hour and $3\frac{1}{4}$ tons at 75 miles per

* There is no uniformity in different countries in the symbols used for types of locomotives. This paper follows American and British steam practice, thus 4—6—0 indicating a leading 4-wheeled bogie, 6 coupled driving wheels and no trailing pony or bogie. 2—8—0 indicates a 2-wheeled leading pony, 8 coupled driving wheels and no trailing pony or bogie. 4—4 + 4—0 indicates an articulated locomotive with leading and trailing bogies and 4 driving wheels in each half.

† W. E. DALBY. "Characteristic Dynamical Diagrams for the Motion of a Train during the Accelerating and Retarding Periods." *Proceedings of the Institution of Mechanical Engineers*, Parts 3–4, p. 877, 1912.

* F. LYDALL. "Electric Locomotives." *Journal I.E.E.*, vol. 51, p. 739, 1913.

hour. If such a locomotive could be built it would more than meet the case at the maximum speed, but with series characteristic motors its curve of draw-bar pull plotted against speed would not be quite like any of the curves in Fig. 2, and it would develop nearly 2,500 h.p. at 40 miles per hour, and more at starting. Such locomotives would entirely alter the conditions under which British passenger traffic is worked.

One object of the series winding is to saturate the field of the electric motor at starting, and provided the field is saturated no extra current through the winding is of any use. The field can equally well be saturated by separate excitation, which opens out the possibility of a shunt characteristic with variable speed for the continuous-current motor, voltage variation already providing several running speeds with the single-phase motor.

The very interesting experimental line equipped by the Lancashire and Yorkshire Railway for 3,500-volt continuous-current electrical working between Bury and Holcombe Bridge has two motors on its motor coaches permanently in series and a motor-generator for providing current at 100 volts for the auxiliary service of control, brake pump, lighting, and heating. The same principle could be used for exciting the field, and it is suggested that such a method of obtaining the series characteristic at starting and the shunt characteristic for higher speeds is worthy of consideration.

The two Prussian State Railway locomotives already referred to are both single-phase locomotives working the driving wheels through connecting rods, and come much nearer to Mr. Lydall's idea for fast passenger service than any other type; but they do not reach it, and it seems fair to say that up to the present time no electric locomotive has been made suited to our maximum loads which can replace the fast passenger steam locomotive in this country.

Turning from the engineering to the economic side, and assuming a suitable electric locomotive has been built, a very rough estimate may be made of the cost of working, more with the purpose of showing the direction in which economies are desirable than of giving any figure that can be used for estimating purposes.

The annual cost of a steam passenger locomotive, averaged over all the different types in use on a railway carrying passengers, goods, and minerals over not less than 2,000 miles of route, and hauling its own locomotive coal, may be taken to be £825 for such items as do not vary with the mileage run or only vary to an extent which will not affect this first approximation. These include capital charges (which are taken at 6 per cent for interest and obsolescence), administration and management, wages of drivers and firemen, oil and small stores, maintenance repairs and renewals. To this is to be added the cost of coal and water, varying more or less directly with the mileage, which for passenger service may be conveniently taken as the train mileage. The annual cost of coal at about 9s. per ton per 10,000 B.Th.U. averaged over the whole working together with the cost of water may be taken to be £350, giving a total for the year of £1,175 inclusive of capital charges. This is a mean for all locomotive types working an average passenger mileage of 10,000,000 train-miles per 1,000 miles of route. During the year a passenger engine may be expected to run between 25,000 and 30,000, or say 27,000, passenger train-miles, so that the mean cost for locomotive expenses (including locomotive capital charges) per train-mile will be 10½d.

Of the above sum of 10½d. per train-mile 3d. per train-mile will represent the cost of coal and water. After the coal strike in 1912 the cost per ton went up 2s., but neglecting its present high but fluctuating value, and taking the cost of the best English coal used at 12s. 6d. per ton, to which 3d. per train-mile corresponds, cheap coal in this country is one of the factors making against railway electrification. The cost of coal burnt in a large modern generating station producing electricity for hauling trains by an electric locomotive is less than half the cost of coal for doing the same work in a steam locomotive. In America coal costs about the same as in England, but in France the 3d. per train-mile for coal and water would be at least 6d., and in Switzerland and Italy 9d. or more. The influence of the cost of steam locomotive coal in non-coal-producing countries, more especially where water power is available for generating electricity, becomes obvious from this form of analysis without claiming any great exactitude for the actual figures given.

In the paper on 2,400-volt electrification already referred to, Mr. Hobart* works out the efficiency of a Pacific type 4—6—2 steam locomotive between the heat value in the coal in the tender and the work done at the draw-bar, and correcting his constants for the results obtained with the largest modern English locomotives using coal of a calorific value of about 15,000 B.Th.U. per lb., the value of this efficiency is 3¼ per cent. Allowance is made in this figure for the coal used in firing up and remaining in the firebox at the end of the journey. He also quotes the actual efficiencies obtained between the heat value in the coal in the bunkers of a large modern electric generating station using similar coal and the work done at the draw-bar of an electric locomotive for similar work, and finds it to be 6 per cent after his constants have been altered to suit English conditions. Working from these efficiencies the result is obtained that the cost of electricity per passenger train-mile is about the same as the cost of coal and water per passenger train-mile hauled by the steam locomotive, provided that electricity can be bought at ⅓d. per kilowatt-hour.

Weight for weight the electric locomotive costs about twice as much as the steam locomotive, but for the same adhesive weight the electric locomotive weighs some 30 to 40 per cent less than the steam locomotive. Electric repairs and renewals cost less, and the net result is that the annual cost of the electric locomotive will be in the neighbourhood of £1,250 per annum, assuming the same rate for capital charges.

But while the passenger steam locomotive only runs on the average 27,000 train-miles in the year, spending 75 per cent of the time out of active service, the electric locomotive, which need only be in the shops for one month out of the 12, will not spend more than 50 per cent of its time out of active service. The electric locomotive can run at least 40,000 passenger train-miles per annum. There is not much experience to go on, and that experience has been wholly obtained in other countries. The suburban working in London where electric locomotives are used is so restricted that no figures are obtainable which can

* *Ante*, p. 297.

be compared with steam working. Multiple-unit motor-cars run 45,000 to 50,000 miles per annum.

If these figures are accepted, the cost per train-mile with the electric locomotive (including locomotive capital charges) will be 7½d., always assuming that electrical energy can be bought at ⅓d. per kilowatt-hour.

It must again be emphasized that these figures can only be considered as a first approximation to the truth, and they will differ for different railways. But assuming that for a railway running 10,000,000 passenger train-miles per 1,000 miles of route, the conditions enabled electric locomotives to run 40,000 miles annually, so that a saving of 3d. per train-mile was secured by electrification, there would be a possible annual saving due to electrical working of £125,000. If capital charges (interest and amortization) were 6 per cent, this would represent the charges on a capital of £2,100,000 per 1,000 miles of route, or £2,100 per mile of route. This sum would certainly not cover the corresponding electrical equipment of the line on an overhead system, inclusive of contact wire and structures, distributing cables, bonding, and sub-stations.

The only items for which a reduction in costs may be expected are the cost of electricity and the capital cost of electric locomotives. No great reduction in the cost of the former can be expected so long as railways generate their own electrical energy, as there must be a diversity of load and generation on a scale far beyond railway requirements to secure an appreciable reduction in price. If electrical energy could be bought at ¼d. per kilowatt-hour, and the electric locomotive could be made for £50 per ton, the cost per train-mile in the above estimate would be reduced to about 6d.

The problems in front of the electrical engineer who would compete with the passenger steam locomotive are therefore first to design an electric locomotive that will do what the steam locomotive does at high speeds; secondly, to reduce the cost of the electric locomotive (which will come about when there is sufficient demand for it); and thirdly, to be in a position to buy electrical energy at something approaching the ⅛d. per kilowatt-hour which forms Dr. Ferranti's ideal.

3. Fast or Slow Goods and Mineral Service.

Reference has already been made to Mr. Lydall's paper on electric locomotives, and his proposals for a fast passenger locomotive. Two types are also suggested by Mr. Lydall for goods locomotives,* one to give a draw-bar pull of 12½ tons at 17½ miles per hour and 4 tons at 25 miles per hour, and the other to give 12½ tons at 25 miles per hour. Both are to be able to run light at 40 to 45 miles per hour.

Reference to Fig. 2 will show that the 2—8—0 steam locomotive can fulfil conditions about midway between the two. Adhesion would allow of a 20-ton pull at starting, the weight on the coupled wheels being 62½ tons, and when the locomotive is moving and up to about 8½ miles per hour the pull is 13 tons.

For a fast passenger service in this country it has been argued that to compete with steam a suitable electric locomotive has yet to be designed and made for about half its present cost, while it must use electricity at rates not yet in view.

* *Journal I.E.E.*, vol. 51, p. 746, 1913.

For goods and mineral service the outlook is different, and in consequence the form of analysis from averages which was admissible to prove a negative is not admissible to prove a positive. For goods and mineral services each individual case must be worked out on its merits. It may, however, be said that if the same analysis be followed out in the case of the average cost of an electric locomotive for goods working as has been done for passenger working, the same comparative ratio of cost between coal and electricity per train-mile would hold with electricity at ⅛d. per kilowatt-hour—the price at which it can in some cases be obtained to-day—in place of the ⅓d. per kilowatt-hour assumed for passenger service.

Complete analyses on different lines have recently been made for American conditions in the papers already cited by Messrs. Hobart* and Kahler † with favourable results, and by Mr. A. H. Babcock ‡ with unfavourable results for mountain-grade electrification. The methods of analysis are well worth study by all interested.

Considering English conditions the chief difference between goods service and passenger service is the reduction in the annual train mileage run by the steam locomotive. Whereas for steam passenger service it was taken to average 27,000, for goods and mineral service it drops to 10,000 train-miles per locomotive. In addition to this the coal per train-mile is nearly doubled.

On the average some two-thirds of the available steam locomotives may be expected to be in steam on any one day, and of those engines in steam the engine mileage will probably exceed the passenger train mileage by little more than 5 per cent. On the other hand goods engine mileage may exceed goods train mileage by more than 30 per cent owing to the many services that the locomotive has to perform other than moving trains from station to station. Each goods engine in steam may not work more than 40 to 50 train-miles per day averaged throughout the year, which gives some idea of the length of time the locomotive is standing in steam and using coal but earning nothing, while nearly one-third of the engines are away under repairs.

It is in this direction that the electric locomotive appears to have its best chance. In America it has been found to be possible at least to double the daily mileage run by a steam locomotive, owing to the ability of the electric locomotive to haul heavy loads at an increased speed while it wastes no energy when standing idle. Instead of more than 30 per cent of the steam locomotive year being occupied in repairs, not more than 10 per cent of the electric locomotive year need be spent in the repair shops.

Fig. 2 shows the available tractive efforts of one or two electric locomotives in America at low speeds, but American conditions are not our conditions, and a locomotive giving a starting pull much greater than the 2—8—0 steam locomotive is of no use for goods service in this country. In America the strength of the draw-gear is such that draw-bar pulls of more than 30 tons are permissible, and trains of 3,500 and 4,000 tons weight can be hauled if fitted with continuous brakes. In British goods and mineral service the limiting factor is the strength of the draw-gear,

* *Proceedings of the American Institute of Electrical Engineers*, vol. 32, p. 1015, 1913.
† Ibid., vol. 32, p. 1057, 1913.
‡ Ibid., vol. 32, p. 1783, 1913.

which is tested to 50 tons and with a factor of safety of 4 is supposed to be worked at a maximum load of 12 tons.

English railways started by hauling vehicles belonging to the public, and they have never ceased to do so. At the present time it is estimated that there are some 700,000 wagons * owned by traders liable to be run on British railways. They are built to specifications which have been issued from time to time by the Railway Clearing House, but draw-gear starts to deteriorate from the time it is first put into service.

On lines with no adverse gradients it is possible at times to haul trains of 100 wagons weighing 1,600 tons, but that is the exception in this country. Goods trains of 56 wagons weighing 900 tons can be taken by a 2—8—0 engine up gradients of 1 in 150, and of 24 wagons weighing 380 tons up gradients of 1 in 50, without endangering the draw-gear, and as a general rule longer trains than 60 wagons are not conveniently dealt with in the usual lay-by sidings, although trains of 100 wagons can be handled in suitable places. We are not, therefore, really limited in our train weights by the maximum size of steam locomotive which can be built within the restricted British load gauges (restricted, that is to say, as compared with America and many European countries), but by the strength of draw-gear and the lay-out of sidings.

While the wagons owned by railways can have their draw-gear maintained against inevitable degradation by fatigue and wear, the privately-owned wagon is not in the same position. Unless the whole method of working goods traffic in this country is to be altered, a locomotive is not required to give a draw-bar pull of more than 12 to 14 tons after starting, and even then the failures of draw-gear will always be considerable with the shocks when starting a loose-coupled train and with the stresses due to unequal braking. A large number of goods and mineral wagons are still loose-coupled. This reduces the necessary starting pull, but at the same time makes it essential that this pull should be increased gradually or the shock on successive coupling chains will break them. The draw-bar pulls of the American electric locomotive shown in Fig. 2 if used on a British goods or mineral train would merely break the couplings.

One class of traffic in this country is happily free from this drawback, and that is the mineral traffic of the North-Eastern Railway on the north-east coast. The railway owns the coal and ore wagons, or the greater proportion of them, and not being handicapped by traders' wagons can maintain their draw-gear at the required standard. They are fortunately situated for the bulk of their heavy mineral traffic in a district served by the North-East Coast electric power companies, and can buy electricity cheaply.

The mineral line between Shildon and Newport (Middlesbrough), a distance of 18 miles, is now in process of being electrified, the length of single track and sidings amounting to 50 miles. Two sub-stations on the route will supply continuous current at 1,500 volts, for the most part through overhead conductors and through a protected conductor rail in places where an overhead conductor is inconvenient.

The locomotives will be able to start and haul mineral trains weighing 1,400 tons at a speed of 25 miles per hour on the level, and start an 800-ton train on a grade of 1 in 100.

Apart from suburban electrification this is the most interesting railway electrification which has been contemplated in this country, and if successful it will undoubtedly be the real beginning of goods electrification. Its working this year will be a matter of great interest to electrical and railway men.

While the cost of everything in the industrial world has been going up, increasing the expense of many things that a railway has to buy, including labour, the railways have not hitherto been able to increase the price at which they sell transport. In passenger service not only have working expenses increased in harmony with the general rise in prices, but the railways are constantly being required to improve their services by providing increased comfort, lighting, and heating, as well as by the provision of restaurant and sleeping cars (which increase the weight hauled out of all proportion to the increase in the number of passengers), and by the speeding up of the trains. Third-class passengers form about 95 per cent of the total number of passengers carried, and as an indirect result of the so-called Cheap Trains Act of 1883 third-class single fares have been fixed at a maximum of 1d. per mile. Therefore, however much expenses may increase, practically no corresponding increase in the revenue from passengers can follow; and it is largely for this reason that the substitution of the electric locomotive for the steam locomotive can only be considered if the result is going to reduce the ratio of expenses to gross receipts by such an amount as will increase dividends.

Rates for goods and minerals are somewhat different. By the Railway and Canal Traffic Act of 1894, in order to increase a rate within the maximum which has been fixed by Parliament the railway must, if challenged, prove before the Railway Commissioners that the increase is reasonable. Even if a rate is lowered experimentally to assist some new form of traffic, it cannot afterwards be raised to some figure below the parliamentary maximum when the business can afford it without the liability of an application to the Railway Commissioners, when the onus of proof would be upon the railway. It has generally been held that the latter could only succeed by showing a proportionate increase in expenses since the lowering of the rate. This liability has undoubtedly worked to prevent the lowering of rates. By the Railway and Canal Traffic Act of 1913, passed as a result of the railway strike of 1911, a reasonable increase in rates is to be allowed within the legal maximum where the railway can prove before the Commissioners that the increase is intended entirely to meet the rise in wages since August, 1911, the date of the strike. The fact that for a portion of its increased expenditure—although under very special circumstances—a railway has been treated as a commercial undertaking, is distinctly hopeful for electric traction, since it tends to remove one element that makes the raising of fresh capital for railways so difficult.

The methods of electrification available for the consideration of the engineer are varied,* but for goods working involving the equipment of sidings some form of overhead equipment seems imperative. Continuous current, single-

* In the discussion on M. Parodi's paper at the Paris Meeting in May, 1913 (*Journal I.E.E.*, vol. 51, p. 613, 1913), this figure was given as 500,000, and is here corrected from further information.

* See Dr. Gisbert Kapp's address as President of Section G at the British Association's Birmingham meeting, 1913.

phase with commutator motors, single-phase with split-phase motors, and single-phase with mercury arc rectifiers and continuous-current motors, and three-phase with induction or cascade motors, are all possibilities, and each has to be considered on its merits. It is not within the scope of this paper to discuss systems, but it may be pointed out that owing to the special conditions of goods and mineral traffic in this country—a few of which have been referred to in this paper—the electrification of goods and mineral lines is likely to begin only in favourable districts, especially with steep grades where the overload capacity of the electric motor and its accelerating ability will enable traffic which is now very slow to be speeded up. This will increase the earning capacity of the existing permanent way without costly re-grading.

The electric shunting engine is a very good example of what has to be done in the matter of suitable design. A shunting engine may be called upon for hours to push heavy trains of wagons at 2 or 3 miles per hour and then to clear away a train of empties at 25 miles per hour. It is frequently called upon to push or pull a heavy loaded train over a weighbridge with a pause long enough for the weight to be recorded while each wagon is on the bridge. This the steam locomotive can do, but the continuous-current series-motor locomotive with continuously rated resistances seems hardly an engineering competitor of the steam locomotive for such work as this. There is far more hope for the single-phase locomotive.

To sum up the position as it appears to the author—the inherent advantages of the electric locomotive for goods and mineral haulage are, first, its ability to haul up to the maximum strength of the draw-gear at more than double the speed possible with the most powerful steam locomotive which can be built within British load gauges; secondly, the ability if necessary to have all axles driven, so that the whole weight of the locomotive is available for adhesion while the weight per axle is sensibly reduced; thirdly, the advantage that any driver can work any locomotive, which is not the practice in this country with steam locomotives; fourthly, the ability to run annually at least twice as many train-miles as the steam locomotive, partly due to increased speed and partly due to less time spent in the repair shops and for cleaning; fifthly, the saving of all coal wasted by the steam locomotive when getting up steam, standing in steam, and left in the firebox at the journey's end, with the result that with electrical energy at ½d. per kilowatt-hour the bill for current per mile is about the same as the bill for coal and water per mile; sixthly, the possibility when the strength of the draw-gear permits of loads being hauled quite beyond the capacity of any steam locomotive that can be built within our load gauges. The electric locomotive takes its power from a generating station and not from a moving boiler; it can therefore be designed to give its maximum draw-bar pull at any desired speed. It is for the electrical engineer to make the most of such advantages.

DISCUSSION ON

"BRITISH PRACTICE IN THE CONSTRUCTION OF HIGH-TENSION OVERHEAD TRANSMISSION LINES." *

NEWCASTLE LOCAL SECTION, 12TH JANUARY, 1914.

Mr. Hunter.

Mr. P. V. HUNTER: The author commences his paper by considering when overhead lines are justified as compared with underground cable systems, and gives a comparison of capital costs for various voltages which clearly indicates that the higher the pressure the greater is the advantage that overhead lines possess. Personally, I think overhead lines should not have so much advantage as that shown in the paper. I think the price given for 11,000- and 20,000-volt cables can be substantially reduced. With present standards, cables have a factor of safety which is unnecessarily conservative. For instance, standard 11,000-volt cables could quite properly be used for 20,000-volt working, with a consequent modification in the price from £2,100 to £1,550. I notice at the end of the paper that the author suggests the formation of a Committee for the standardization of transmission lines, but I sincerely hope it will not be formed until a great deal more experience has been obtained, as I attribute the high cost of underground cables to the standards having been settled too early and to the delay in revision. The question of factors of safety is referred to on page 179; I am sure that everybody engaged on the construction and operation of overhead lines will agree with what the author has said, and I am of the opinion that Mr. Trotter has been well advised in recommending the factors of safety which have been adopted by the Board of Trade. A point in which I am much interested is protection against atmospheric disturbances. Opinion is, I think, leaning towards the view that tens of thousands of pounds have been wasted on useless (not to say harmful) forms of lightning arresters. I have no faith in the horn-gap, nor indeed in any apparatus which introduces an air-gap in the path of a discharge. In connection with this I think the air-gap in series with the electrolytic arrester militates very much against its satisfactory operation. From experience of these arresters I am not able to say that they are satisfactory as at present used. The form of apparatus which is suggested by the author is the Moscicki condenser. In so far as it dispenses with a spark-gap I think it must be an improvement on other types. If, however,

Mr. Hunt

* Paper by Mr. B. Welbourn (see pp. 177 and 217).

unter. it is assumed that the function of an arrester is to dissipate the energy of a surge I am afraid the apparatus would become very large and expensive if it had really serious work to do. The author refers to the practice in this district of dispensing with ordinary arresters and protecting the end-turns of transformers. This method was not originated for pole-line work, but was in use long before pole lines were adopted. I do not believe that the transformer has much to do with the matter. The energy of the surge is, I think, dissipated in the cable dielectric, and for this purpose every overhead line is run underground for a short distance before entering a sub-station. Overhead lines have no dielectric hysteresis, as the dielectric is air, assuming of course that the working pressure is below the corona limit. A length of underground cable in an overhead line may from this point of view be regarded as an improvement rather than otherwise. There is, however, no doubt that the insulation at the junction between the overhead line and cable must be liberal. If this is carefully attended to, lightning (other than direct lightning strokes) and surges should give no serious trouble in this country. The author also refers to the pressures which may occur on bare telephone lines from various causes; but he has not mentioned what I think is perhaps the most important case, namely, when a wire breaks and falls to the ground and the currents are no longer balanced in the conductors. This produces a dangerous voltage on the telephone line just at the time when it is most wanted for use. Bare telephone wires on overhead lines should be entirely prohibited.

Reference has also been made to the Merz-Price and Merz-Hunter protective systems and the time taken to operate them, but the figures given in the paper refer to the relay and not the switch, as the former owing to the mass of moving parts does not operate so quickly. Switches are now being made by at least three manufacturers to break circuit in 1/20 second. This figure is not so small as that given by Mr. Welbourn, but even when added to the time taken for the relay to operate it is quite sufficient to prevent a live wire touching the ground, assuming of course that the relay is of a type that begins to operate immediately the wire breaks.

nt. Mr. F. O. Hunt: The author refers in his paper to the time taken for automatic switches to open the circuit as 1/80 second, but I am glad to learn from Mr. Hunter that this refers to the relay and 1/20 second to the main switch. The important matter is the combined time of the two; for if this can with certainty be brought well within the time taken by the fall of a wire, there is a very strong probability that the operation will be over before the wire could reach a human being. This has an obvious bearing upon the height at which conductors should be placed above places where men may occasionally have to work. The chief difficulty lies in the great mass of the current-carrying and mechanical parts of switches for high power. This mass involves correspondingly great forces in order to bring about sufficiently rapid acceleration; yet in the process of closing the switch these forces have usually to be overcome by hand operation. It is necessary to aim in design at lightness, even of the balanced parts, in order to keep down the total moment of inertia. The use of cable telephone systems seems perfectly sound practice, but I should be glad to know whether any trouble has been experienced with regard to the distance over which it is possible to speak under these conditions. Mr. Hunt.

Mr. J. R. M. Elliott: I am afraid that I cannot speak with any practical knowledge of the building of heavy power lines, my experience having been confined to the construction of telegraph lines, but there are several points to which I should like to refer. Touching on the statutory powers possessed by the Postmaster-General, I can hardly agree with the author when he states that the procedure to be followed is so cumbersome as to be almost useless, because as a general rule the Department has very little difficulty in obtaining from road authorities the necessary permission for the erection of lines. If similar powers could be obtained by electric supply companies, I think considerable advantage would be derived from such facilities. Mr. Elliott.

Route maps.—I am afraid that the maps to which the author refers are too cumbersome to meet requirements. When it is understood that surveys have to be made in all kinds of weather, the insertion of details on the route map would be an inconvenient arrangement. In my opinion it would be better to have a stiff-backed pocket-book, say 6 in. by 4 in., each page being ruled with horizontal lines about 1 in. apart, so that as the survey proceeded particulars associated with each pole or span could be recorded in the ruled off spaces.

Safety factors.—The author is doubtful whether the Post Office figures are sufficiently conservative. The question of strength in the building of a line is, after all, a matter of cost. It would no doubt be possible to construct open lines to withstand the severest storm, but in view of the desirability of restricting the enormous expense entailed thereby, the present safety factors have been adopted by the Department. Telegraph lines may frequently be seen to be damaged in heavy snowstorms, but these breakdowns do not always occur in the same places, and, after all, the average number of times which a line is subject to breakdown is only once in 10 years.

Wood and steel poles.—The author mentions that poles creosoted by the "Rüping" process are cleaner to handle than ordinary creosoted poles. From my own personal experience I find that the amount of free creosote on the surface of timber newly treated by the Rüping process is as great as that on timber creosoted in the ordinary manner. The principal advantage claimed for Rüpingized poles is that they are adaptable for painting. The Post Office has recently erected a number of these poles at Darlington, and time will show whether the creosote will ooze through the paint. Before applying paint to Rüpingized poles they should be thoroughly planed to obtain an even surface for the priming colour, otherwise the free creosote on the surface will soon make its appearance through the paint, more especially if the latter be of a light colour. Where the amenities of a neighbourhood are to be considered this is of considerable importance. With regard to the use of steel poles, I quite agree with the author that these should be avoided. Owing to the impossibility of inspecting the insides of the tubes, their actual condition can never be definitely ascertained, and many accidents have occurred from steel poles breaking whilst men have been engaged in work upon them.

Aluminium conductors.—I am very glad to know that the use of aluminium by supply companies is being extended.

Mr. Elliott. Experiments were made some years ago by the Post Office with aluminium wire for line-conductor purposes, but the results then obtained were not sufficient to justify its adoption; the light wires were blown about to such an extent in the wind that they quickly broke off at the insulators. The success attending the use of aluminium by supply authorities may be due to the conductors being stranded, and being of such a weight that they do not blow about as would be the case with lighter wires. I notice from the table of suggested tests for hard-drawn aluminium that the author makes no reference to a "twist" test. I do not know whether this omission is intentional, but in my experience such a test is of even more importance than a wrapping test.

Telephone wires.—The arrangement whereby the line wires at every fifth pole are transposed is of course beneficial, but if the question of cost is not a material factor greater efficiency will be secured by revolving the wires a quarter of a turn in each span.

Mr. Elder. Mr. C. E. ELDER: Insulators are one of the most important parts of a high-tension line, and therefore too much attention and care cannot be exercised in connection with the packing and fixing of them. I do not advocate cement of any kind for pin-type insulators, as my experience in this direction has been very unfortunate, especially with cements which have to be liquefied by heating. I am strongly in favour of hemp twine packing, as mentioned by the author, and I consider that insulators should never under any conditions be fixed by unskilled persons. A few points have to be considered in order to pack an insulator successfully with hemp twine. The pin must be made the correct size, with due allowance for the packing, and with a rough cut thread to grip it. The hemp twine must be the correct size so that only one layer is required, and also the packing should not be too tightly spun, so that it beds itself into the threads of the insulator. It is also important to insert a felt wad at the bottom of the insulator hole. There is also a method of tying the ends of the packing which I will not mention in detail. I may say that insulators packed in this manner will stand the full terminal stress of a line without moving in the slightest, and I have seen them in use on conductors of 0·15 sq. in. section. The only difficulty which I have experienced in connection with the twine packing system is that the holes in the insulators vary a little, and of course with a standard size of twine this may make the insulator either too slack or too tight. It is therefore important that each new delivery of insulators should be examined, and a little adjustment of the packing puts matters all right if there is a variation in the holes.

Pole-line work has many fascinations, and to be a successful constructor one must be prepared to tackle details. Underground cables are laid in the earth out of sight, and are forgotten until something happens. It is not so with a pole line, and I wish to make a claim for what I might term the artistic beauty of pole lines. There is no doubt that well-constructed lines will in the future have a considerable influence in connection with way-leaves, especially in and near residential districts, and is it surprising that this question of appearance is raised when there are such unsightly telegraph and colliery power lines? Even in our public streets we are constantly confronted with crooked tramway poles, evidently set intentionally from 6 in. to 9 in. out of plumb. These conditions create bad impressions and are not helpful in the advance of pole-line work generally. It is gratifying to notice from some of the author's lantern slides that such points are receiving due attention. I do not for one moment say that appearance is everything. I would not even allow that it should add to the cost; it is simply a question of careful lay-out and close supervision, as the material for extra-high-tension lines must necessarily be of the best quality, and I think it is the duty of every engineer who has to deal with pole lines to keep this point in view. Mr. Elder.

Mr. H. BRIDGES: In the construction of high-tension overhead transmission lines efficiency, reliability, and continuity of supply are of first consideration. To secure these conditions it is essential, as the author has emphasized in the early part of his paper, that every detail, however small and apparently unnecessary, must be given close attention. In all classes of engineering, especially in the erection of machinery, it is very important that the greatest attention be given to every detail, or otherwise much damage and inconvenience will result. This also applies equally to the construction of overhead lines. Taking into consideration the severe weather and various other conditions to which overhead lines are subjected, the neglect of small and insignificant details, bad workmanship, and the "that will do" method are bound to lead to serious and constant breakdowns. The maintenance of overhead lines must also be taken into consideration, as good design and construction will considerably reduce the maintenance costs and also increase the life of the lines. In the past the maintaining of lead-covered pilot and telephone cables suspended with leather hangers to a catenary wire has been a very costly item and was threatening the practical use of the overhead suspension of lead-covered cables. During high winds the long leather hangers would get blown out of position, causing long sags in the cable, which resulted in the cable breaking down. Many months have been taken up in carrying out repairs and the re-spacing of hangers; and before some of the longer lines could be finished the whole of the work previously done would have to be repeated, the hangers being again displaced and the cables thus further damaged by another wind storm. One bad feature was the long hanger then in use. It is very important that the hangers should be as short as possible, so that in a high wind the catenary wire and the cable will swing together. If the hanger is long, even if clipped to the catenary wire, an uneven swinging will result, causing a flapping of the cable and eventually leading to breakdown. The use of the "Elder" hanger has solved the problem of the suspension of overhead cables, and is a combination of the necessary points required, viz. a short hanger and the prevention of displacement by winds. Since this hanger has been adopted the maintenance costs are practically nil. The arrangement also adds considerably to neatness, as can quite readily be seen by comparing the old and new method of suspension. Mr. Bridges.

With the advent of the "Merz-Hunter" protective system for overhead lines the pilot cable is not required, and where telephone communication is not necessary, or can be given by some other source, the suspension of overhead lead-covered cables need not be considered. On all

ges. high-tension networks of any importance telephone communication with the source of supply and between sub-stations is very necessary. To run bare telephone wires on the same poles as the power lines is not advisable, as the continuity of telephone communication during storms when the power lines have been damaged is very essential. This cannot be guaranteed with bare wires, as these would, no doubt, be the first to suffer; and to have power lines out of commission and under repair without telephone communication would be very serious. To secure the continuity of telephone communication it is therefore necessary to run lead-covered telephone cables suspended to catenary wires, and the "Elder" method of suspension is the only one which at present can be relied upon to give continuity.

rd. Mr. J. R. Beard: In connection with the slides showing an actual overhead line after a heavy snowstorm, I was impressed by the fact that while all the power wires were coated with snow to a diameter of about 5 in., the lead-covered pilot cable and its catenary wire were apparently quite free from snow. I should be glad to know whether the author can suggest any explanation of this.

d. Mr. W. P. Ward: I have only two points to mention. One is with regard to earthing, a point on which the author lays great stress, and I should like to describe an earth-plate which was recently shown to me. It consisted of the usual cast-iron plate about 2 ft. square, across the centre of which the copper earth-strip was sweated and bolted. The advantages of a plate of this description are: (1) better contact between the earth-strip and the plate and (2) that no joint is required between the bond ends and the earth-strip. The other point is in reference to the erection of the inverted type of trifurcating box for split conductor cable. It would be a very good idea to assemble the cables in these boxes at the bottom of the pole and make a joint afterwards. The author informs us that the life of steel poles in a Lancashire industrial town was 14 years; on this basis I should like to know what he estimates the life of the Blyth towers to be.

ott. Mr. W. A. Gillott: The author mentions that great attention must be given to details. In this matter I entirely agree with him, but I have found that the most important item to watch is the man who is doing the work. The slide showing the accumulation of snow on the lines is of very great interest to me. It brings to my mind an instance about 4 years ago when I saw some Post Office wires of No. 14 gauge increased to 3 in. in diameter due to the accumulation of snow and ice upon them. I was in the vicinity when the poles broke due to the extra weight. In the same district a high-tension pole line with aluminium conductors did not suffer to such an extent. The accumulation of snow and ice on the wires, which were 0·6 in. in diameter, did not amount to 3 in. as in the case of the Post Office line. This is probably due to certain chemical action on aluminium conductors, to which the author refers. The question of hanging telephone cables by catenary wires, using the method described by the author, is of very great importance. On one of the pole lines which we constructed we had a considerable amount of trouble with the telephone cables breaking at the hanger supports; the breakage mostly occurred near the poles. In this instance the poles were approximately 80 yards apart, which, with Mr. Gillott.
the use of aluminium conductors, necessitated a sag of approximately 8 ft. in the centre of the span. The adoption of a newer method got over this difficulty. The author mentions the cushioning effect of insulated pins. The old method of using Phelps' metal is to be deprecated; hemp or spun yarn and tallow are very much better. With regard to binding wires, this is a point which should be very closely watched by the clerk of works. I have seen cases where solid conductors were used. The workmen had actually used as a binding wire a piece of the line conductor which had a cross-section of 0·025 sq. in. With regard to the actual erection of the poles, some contractors have a weakness for using long spikes for pushing up the poles, and also for using climbing irons for mounting the poles. This gives the poles a very untidy appearance and becomes a nuisance when men have to climb the poles for inspection purposes or repairs.

Mr. Gregory: Which in Mr. Welbourn's opinion is Mr. Gregory.
the safer method of supporting a three-phase line? Should the three conductors be placed side by side horizontally, or should they be placed one above the other vertically? The former method seems open to considerable danger from short-circuits, due to the swinging of the wires in a high wind. Wires swing in an arc of which the radius is equal to the amount of sag, so that conductors spaced 3 ft. apart horizontally and with a sag of 6 ft. in the centre of a span might under certain conditions touch when swinging only some 15 degrees from the perpendicular. On the other hand, conductors hung in a vertical line will never touch when swinging, but are liable to the snow-loading troubles mentioned in the paper. I should like the author to state which method, from his experience, he considers the better job.

Mr. G. L. Porter: On page 191 the author states that Mr. Porter.
where lead-sheathed telephone cables are used ordinary low-tension telephones may be employed; but he recommends the installation of spark-gaps, etc., to protect the user from shock in case a fault current in the sheath induces a pressure in the cores. Quite apart from the inability of the spark-gap, which acts after the voltage rises, to prevent a shock, I would point out that the cause which the author gives is small compared with another cause of shocks. Unlike underground cables with heavy lead sheaths, overhead lines possess only a poor return path for fault currents in the steel catenary and the lead sheath of the telephone cable. The return path through earth is also poor. A good earth-plate has a resistance of 4 ohms, which means 8 ohms for the two in series in the return path. The outgoing copper resistance of a heavy line may only be, say, 4 ohms per phase. It follows that in the case of an earth fault near a sub-station two-thirds of the pressure-drop in the circuit is between the earth-plate (including all connected to it) at the sub-station and the earth-plate at the power station. This can be—and obviously has been in certain cases—several thousand volts. If spark-gaps and heat coils are used at both ends of such a line they promptly put that telephone out of commission just when it is required. Apparently the solution is to employ spark-gaps at one end of the line only, and at the other to insulate the user from the instrument or—what is probably cheaper—from the building,

Mr. Porter. *e.g.* by means of a rubber mat. "Split conductor" lines—especially in the heavier sections—have an advantage to which I would draw attention, namely, the considerable reduction in reactance. Comparing some existing 3-conductor and 6-conductor lines of equal ohmic resistance (0·16 ohm per 1,000 yards) the reactance is 0·25 ohm and 0·15 ohm respectively per 1,000 yards. This makes a big difference in the pressure-drop when feeding the usual induction motor load.

Mr Vernier. Mr. C. VERNIER: I have already taken part in the discussion on this paper in London, so that I will confine myself to points with which I have not already dealt. The table on page 178 illustrates a point of interest in connection with the statement which one still hears, even in these days, that any advantages gained by centralizing generating plants are frequently nullified by the cost of the transmission system. With a current density of 190 amperes per phase—with which the overhead lines will deal comfortably, although this is quite the limit for the 20,000-volt cables—a 0·1 three-phase line will deal with 6,574 kw. On this basis, the capital cost per kilowatt transmitted per mile is 2s. 10d. for the overhead line, and 6s. 5d. for the underground cables. Thus, with an overhead line, for every pound sterling saved in capital cost by erecting a large station as compared with a small one, it is possible to transmit 1 kw. over a distance of 7 miles. Transmission losses cannot of course be entirely neglected, but become relatively insignificant owing to the greater efficiency of the larger generating units and the reduced cost of generation resulting from improved load factors and reduced labour charges. I agree with Mr. Hunter that it would perhaps be fairer to compare the cost of 11,000-volt cables against the cost of 20,000-volt overhead lines on account of our somewhat excessive thicknesses of dielectric, but even so the saving in capital cost by the use of overhead lines is still nearly 40 per cent, an amount which cannot be neglected. I see that the costs given for the overhead lines in this table have been criticized by speakers at other local sections, and in this connection I should like to say that lines have been, and are still, frequently erected by non-statutory undertakers for half these prices, or even less; but it is unnecessary to add that such lines do not comply with the Board of Trade requirements in many respects, and are of such a character that they give rise to the idea which commonly exists that overhead lines are unreliable and expensive to maintain. Many of such lines give constant trouble and frequently require reconstruction in a very few years. The figures given in the table are representative of the very best work in each case; and on the other hand I know that some of the lines illustrated by the author in his lantern slides cannot have been erected for anything like these figures.

On the question of reliability of operation, I need only say that it has been the policy of the power companies in this district for some years past never to lay an underground high-tension transmission cable if it is at all possible to erect an overhead line; and while such lines have not reached the almost absolute perfection of underground transmission cables, yet with the ring-main system it is possible to give a satisfactory and quite reliable supply. Some of the most important services to which electric power can be applied, such as pumping and ventilating in mines, are now given on quite an extensive scale in this manner. Mr. Vernier.

With regard to maintenance, I am unable to give actual figures, as it is not our practice to keep separate maintenance costs of different classes of mains, but I estimate that the maintenance cost of our high-tension lines is not more than 2–3 per cent per annum in normal years, that is, years without exceptional storms such as that of last year. In support of this statement I may say that we employ only 4 linesmen and 2 patrol men, who deal with the maintenance of over 100 miles of high-tension lines, including a somewhat greater mileage of suspended lead-covered pilot and telephone cables, and also with the maintenance of 12 overhead distributing networks and a large number of short distributing lines. This result could not possibly have been achieved without the very great care which is expended on the design and workmanship on these lines in the first instance. All lines should as far as possible receive a thorough overhaul every year during the summer months, when necessary renewals can be made and the equipment kept up to a high standard. Every 5 years or so it is also good practice to renew binders, re-sag the wires, plumb poles, and generally give greater attention to the upkeep of the line. I see no reason why lines substantially constructed in the first instance and regularly maintained in this manner should not have a life of at least 30 years, or as long as the poles last. The erection of insulators suitable for ultimate use at higher pressures is in my opinion good practice up to a certain point, and we have for the past year or two given up making any difference in design for lines between 6,000 volts and 20,000 volts, all our lines being standardized for the higher pressure. The extra cost is entirely due to the insulators, and is small, but there follows the great advantage of having standardized material. At pressures above 20,000 volts, however, I think I would adopt suspension insulators, as the present insulators we are using for a pressure of 20,000 volts are about as large as can conveniently be handled. We have found it desirable to use much larger insulators than are employed for similar pressures abroad.

The author hopes the Board of Trade will sanction overhead lines along public roads. This is a question which we have often discussed, but I take the view that generally speaking a public road is not a suitable place for high-tension overhead lines. Our roads in this country are too narrow and tortuous, and often with insufficient room at the side for the satisfactory erection of a heavy line, while it is unusual to find a road without some Post Office wires on one side, and as the Post Office require a horizontal clearance equal to at least $1\frac{1}{2}$ times the height of the conductors, it is seldom that this clearance can be obtained. Notwithstanding all this, I believe the Board of Trade is even now prepared to grant consents for such lines where the conditions are favourable, and where a suitable protective gear is employed. The remarks which I made in the discussion in London on the advantage of "short cuts" should, however, be borne in mind; while if a line is erected satisfactorily along a public road in the first instance, trouble is sure to arise where dwelling-houses are subsequently erected on the frontage of the adjoining land. Mr. Elliott said he thought the Postmaster-General's powers were sufficient and satisfactory. I am afraid he is

not clear that the statement applies only to powers for carrying overhead wires across private land. As I was responsible for the statement originally, I would add that I refer to Section 2 of the Telegraph Act, 1892, and Section 4 of the Telegraph Act, 1908, which deal with the question. I believe there is not a single case on record where the Postmaster-General has exercised his powers under these sections.

On the question of protection against lightning, it may be remarked that in this, as in many other respects, the meteorological conditions in this country are generally favourable to overhead lines when compared with other countries where overhead lines are chiefly used. Severe lightning storms, as is the case with severe snowstorms, are of infrequent occurrence except in certain localities. I do not know what peculiarity there may be in the system conditions on the North-East Coast, but it is somewhat remarkable that all the usual protective devices which are so carefully installed on much smaller undertakings have either never been used at all or have been abandoned. I refer to mains charging gear, roller spark-gaps, and lightning arresters, resulting in a very considerable saving of capital and maintenance cost. Notwithstanding the abandonment of lightning arresters on our overhead lines, our troubles from lightning are certainly no worse than before, and very infrequent. One unusual experience which may be recorded occurred last summer on a line under construction, where a 2-mile section which was not connected up or earthed in any way was affected by a lightning discharge and 10 insulators were punctured.

The suspension of lead-covered cables is a matter to which we have given very great attention, resulting in the method of suspension patented by Mr. Elder. Some extremely rapid failures of many miles of suspended lead-covered cables from crystallization of the lead sheath caused this matter to be fully investigated. There are several points of the greatest importance in connection with this work, and I would add that it is impossible to say that any one Mr Verner of them is of any greater importance than another. These points are as follows: (1) Some hardening material should be put into the lead sheath. (2) All hangers must be of equal length so that each shares the weight of the cable. (3) Such hangers must be as short as possible so as to prevent the formation of ripples which otherwise run along the lead-covered cables, and to compel the lead cable and catenary suspension wire to swing together. (4) Hangers should be spaced preferably 12 in. apart, and not more than 18 in. (5) The hangers should be secured to the catenary wire or lead sheath so as to maintain the regular spacing and prevent creeping of the lead-covered cable. It will be seen that all these features are incorporated in the Elder hanger, and that none of the usual methods of suspension pay proper attention to these essential points. Much damage of suspended lead-covered cables results from the hangers acting as sails and dragging the lead-covered cable along with them when a wind blows in the direction of the line, and especially from the hangers being either too long or too widely spaced. The author states that only high-tension telephone instruments are permissible with bare telephone wires. I thoroughly agree, but I should like to know what percentage of such cases one could find where these instruments are used. Bare telephone wires should certainly never be allowed without them, but here again non-statutory undertakers are allowed to do as they please and use bare wires without them. In conclusion, I should like to ask the author whether he has any experience to show that long spans are safer than short ones under ice loading. In the storm last year it was noticed that the only breakages of conductors which occurred, apart from fusing, were at guard spans, which are usually very short.

The author's reply to this discussion will be found on page 317.

Manchester Local Section, 13th January, 1914.

Mr. C. D. Taite: The author has dealt with a subject which is undoubtedly of growing importance at the present time because overhead lines are developing very rapidly, and those of us who are interested in their erection know very little about what is being done in other districts. If the author's suggestion of a Transmission Lines Committee could be adopted, I think it would be fruitful of very good results by standardizing practice and bringing to the notice of those interested what is being done in other places. On page 178 the author gives a table comparing the cost of underground cables and overhead lines of similar capacity. I do not agree with that table at all. My experience is that the cost of underground work is more nearly 3 times the cost of overhead lines of the best quality. The company with which I am connected usually install duplicate lines or duplicate cables as the case may be, and I have some figures of the actual cost of installing a 0·1 sq. in. underground cable and an 0·1 sq. in. overhead line. The underground cable, in duplicate, cost approximately £2,600, and the actual cost of an overhead line of similar capacity, in duplicate, was £953, which is practically what the author has given for a single line. We always assume that the cost of an overhead line is approxi- Mr. Taite. mately one-third that of an underground cable, a duplicate transmission being taken in both cases.

I know there is a growing tendency to use aluminium conductors, but I think there are still many serious objections to their adoption for overhead lines. In the first place the sag is very much greater; that involves either more poles—and the difficulty of getting wayleaves is very great at present—or higher poles. In the second place it means wider spacing of the conductors, because the swing will be greater; this again means stronger cross-arms. There is also a third trouble, namely, the connection of the aluminium conductors to the underground cables. This is a rather serious problem, and so long as copper is used throughout it is one with which no trouble whatever is experienced.

With regard to cross-arms, my company have adopted, and still use in every case, oak cross-arms. Owing to an accident a high-tension 10,000-volt conductor lay on such a cross-arm for 3 days, and in the course of that time burnt a hole in it. If we had not used oak cross-arms the supply on that route would have been interrupted. In connection with

Mr. Taite. the tying-in of conductors, we have again adopted what Mr. Welbourn objects to, namely, rigid clamps. The type which we have adopted is very simple in construction and has never given a moment's trouble. We claim that it can be erected in all weathers, whereas I think some of the types of binders which the author has described in his paper must require either good weather or particularly skilful men for them to be erected with absolute safety. We have not experienced the trouble which the author refers to in connection with mechanical clamps, namely, friction interfering with the glaze on the porcelain; but the makers of the insulators state that they do not depend on the glaze for insulation. As a matter of fact in some districts where we have had trouble from broken insulators these have lasted for weeks, although it appeared from the ground as if they were almost completely shattered. Neither have we had any trouble from crystallization: our experience extends over a period of 8 years.

We have had one or two cases in which a line has been struck. One occurred last year, and the result was that two miles away from where the lightning flash was thought to have occurred an oil switch broke down. In another case a transformer broke down. We have various forms of lightning arresters, chiefly of the static discharge type, consisting of a number of gaps and carbon resistances. We also have an aluminium arrester at the station, but apparently the storms take place so far away from the station that the aluminium arrester does not seem always to deal with them. American engineers always tell us that the aluminium arrester is the best; but it is by far the most expensive. As pointed out by the author, a great objection to the use of aluminium arresters is that they require daily attention. This renders them quite unsuitable as at present constructed for ordinary static sub-station work. On page 189 reference is made to a practice adopted by Messrs. Merz & McLellan in connecting up their lines at both ends by paper-insulated cables. This is a point I am not quite able to follow, as I think the connections are usually made by bare copper wires. In regard to the terminal boxes shown on page 192, one objection it seems to me is that there might be some difficulty in bringing the conductor either to or from the overhead line. With the ordinary form of dividing box the conductor is carried vertically from the line into the box, but with the boxes shown apparently it is necessary to make a big bend to clear the metal-work of the box, and this brings the conductor so far from the pole that there is very little hope of getting any support for it.

Mr. Watson. Mr. S. J. WATSON: Overhead lines are at the present time one of the most important questions requiring the consideration of those engaged in the electricity supply industry. The reason is quite plain, as has been shown by the figures which the author gives as to the relative costs of overhead lines and underground cables; and here let me say that I disagree with Mr. Taite's figures and support those given in the paper. During the last year or two I have erected a few miles of 6,600-volt lines, and the actual cost of these (which consist of a complete three-phase duplicate line) and of two three-core cables in wood troughing, comes to about £1,250 and £2,450 per mile respectively. This is for conductors of 0·15 sq. in. section. The only serious difficulty which acts against the use of overhead lines is the question of wayleaves. It is one which is exceedingly difficult to handle, and unless it has actually been experienced, I think the difficulties which are encountered would hardly be realized. I have a particular case in mind where we wished to go across a field for a distance of about 200 yards, but on account of the objection of the landowner we were compelled to make a considerable detour which added about £1,200 to the cost of the line. We could have got across the field by erecting about 4 poles and paying the cost of the wayleave. This sort of thing cannot be to the advantage of the industry with which we are connected, and it undoubtedly has tended to restrict the supply to consumers. We must get an Act passed which will make it compulsory for landowners to give wayleaves, as is I think the case on the Continent, and if the Institution can do anything to bring about such a result a lot of good will have been done to further the progress of the industry. The line which we have erected does not differ greatly from the lines which the author has illustrated. It consists of duplicate three-phase conductors with each set arranged in triangular formation on both sides of the poles; 2 ft. 6 in. spacing is adopted, and the poles are of the A type with wood cross-arms. I have been very interested in the various forms of construction which have been shown on the screen. In this connection let me say that in my opinion the best formation is that with only three conductors on one pole; but here the wayleave question comes in again. It is necessary to have a duplicate line, and if two sets each of three lines have to be erected it means a duplicate set of wayleaves and thus a further check.

One of the most important points in connection with overhead lines is that of guarding. The Board of Trade have to call for this protection in the interests of the public, but it often adds appreciably to the cost of construction. It will have been seen what a very heavy and ugly appearance it gives, particularly when the cradle form of guard is adopted. There have been a number of improvements since then. The type we have in use is a split conductor on road crossings, with clips at intervals across the span, so that if the line breaks it is still well out of reach of any animals or people passing along the road. It has quite a neat appearance, far preferable to some of the other arrangements shown, and it is also easily and quickly erected. I have been trying to imagine the feelings of an ordinary landowner who granted a wayleave for the pole shown in Fig. 17 when he saw the complete structure. Such an erection would not be tolerated in many parts of the country. The earthing arrangements have also been referred to by the author. If it is necessary to use an earth-wire—and the Board of Trade are now insisting on this—the proper material to use is copper or bronze. It will last much longer than steel and will give much more satisfaction. I think also that the proper place for the earth-wire is at the top of the pole, because in this position it will provide some protection from atmospheric disturbances. I should like the author to give further information in regard to the troubles experienced from lightning on some of the lines in Wales. Some exceedingly useful experience must have been gained on those lines, as they extend for considerable distances on high land in an area where atmospheric disturbances frequently occur. The triangular guard shown in Fig. 16 appears to

be an exceedingly simple and good arrangement, particularly where it is used on a three-line transmission. It could no doubt be used on a six-line transmission, but it is better for only three lines. The question of aluminium conductors has already been mentioned, and I am inclined to think that one of the points which requires consideration in connection with the use of aluminium or copper is their relative values as scrap materials. There is no question what the value of the scrap copper will be, but there is some doubt about the value of scrap aluminium. If the author would deal further with this point, I think it would be interesting to us.

Mr. J. LUSTGARTEN: We have had quite a number of papers dealing with foreign high-tension transmission work, but in no paper have we been informed that in England we possess 115 miles of high-tension transmission lines at 20,000 volts. And yet, when we consider foreign practice, this is not very much to congratulate ourselves upon. The present paper is very opportune, because the day is not far distant when pressures and capacities in this country will compare more favourably with those of continental and colonial schemes. The author mentions a projected scheme for 40 miles; it would be very much better if the pressure of transmission were about 1 kilovolt per mile. There are a few points in the paper upon which I should like to comment. In the first place, there is the question of the maximum wind pressure. The figure named by the Board of Trade is 25 lb. per sq. ft. of exposed effective area; but to my mind this is too great, especially as the factor of safety is taken as high as 10 for wood poles and 5 for conductors. The wind pressure* for a velocity of 100 miles per hour would only be about 15 lb. per sq. ft., and for a velocity of 65 miles per hour 6 lb. per sq. ft. This last figure would be amply representative of the maximum wind velocity in this country; but to be on the safe side 10 lb. might be taken. The effect of sleet or ice has been left out in Appendix II. I do not think this is altogether wise, as it would affect not only the sag formula, but also the angles given in Appendix XI. Allowance might be made for a coating of sleet or ice about $\frac{1}{2}$ in. thick. The author gives a formula for finding the dip between two towers on the level. The following formula might be added for the dip with the towers on different levels—

$$d_1 = d\,(1 - h/4d)^2,$$

where d_1 is the maximum dip of the wire, h the difference in height of the points of support, and d the dip when the points of support are on the same level, and for the same tension. This formula assumes no wind. If $h > 4\,d$ the wire slopes continuously upwards. A resultant force on an insulator should never be allowed to be upwards. Referring now to the author's data for spacing: it might be of interest to give here an empiric formula which agrees very well with practice—

$$s = (1 + 0{\cdot}1 \text{ kv.}) \text{ feet},$$

where s is the spacing. In the Victoria Falls and Transvaal Power Company's 80-kilovolt line the spacing is 9 ft. With reference to the formulæ for self-induction and capacity, it is perhaps well to point out that the logarithms given are common logarithms and not Napierian. Might I also mention that the formula for capacity of the conductors arranged in one plane is only approximate? It is unfortunate that the author has drawn the vectors in Fig. 3 in the reverse direction to that now agreed upon.

I cannot agree with the author's statement that certain insulators failed because their glaze was cracked. The glaze on porcelain is often of uneven thickness, and is not always perfectly continuous; and unglazed insulators of the highest grade porcelain have as high an electric strength as those that are glazed. The requirements for insulators are that the porcelain should be vitrified throughout; so that there is very little to gain, at the best, from the slight additional thickness of the glazing. Unglazed porcelain attracts moisture and dirt, and on account of the irregularities of the surface would be difficult to clean. For this and no other reason (excepting, perhaps, the use of coloured glazes) a coating of smooth and durable glaze is employed. With reference to Messrs. Buller's specification in Appendix XII, it were best that the "test voltage dry" in the routine tests should be amplified. The reason that this is 20 per cent less than the "flash-over voltage dry" is that the insulator is inverted in a pan of water which reaches to the neck, so giving a smaller flash-over distance. Lines which are exposed to lightning storms and those which are discarding the horn-gap arrester in any of its forms require of their insulators a high safety factor against puncture. These may withstand high electric pressure of low frequency, viz. the "flash-over dry" voltage (Appendix XII), but may not withstand a high-frequency surge giving a pressure rise at the insulator of the same flash-over value. A definite time-interval elapses for sparking over (ionization of the air) to be established, and meanwhile the pressure rise may have reached the puncture value. A high-frequency test would be of some value in determining the ability of the insulator to withstand such shocks. It would appear that insulators with wide and thin shells do not withstand lightning shocks, so that for line pressures up to 40 or 50 kilovolts pin insulators with thick walls between pin and line wire would more easily meet the case. A composite pin, made of wood in the part which screws into the head of the insulator, would relieve the stress, causing breakdown to take place rather through the air path than through the porcelain. In Fig. 6 a special type of suspension insulator—fish-tail interlink pattern—is shown, used for straining purposes, the suspension insulators being also used for leading into stations. In the case of the Ohio Brass Company's type* (used also in the Tata Hydro-Electric Power Company's scheme) there is no difference between the pattern used for suspension and that for straining purposes, except that for straining purposes a higher mechanical strength is needed. In practice, one or two more insulators are used for straining than for suspension purposes; *e.g.* on the transmission line of the Hydro-Electric Power Commission of Ontario 8 are used for suspension and 10 for strain. I have found that there is but little difference in the wet flash-over voltage for these insulators in either the suspension or strain position; as a matter of fact in the former case the drops of water from the topmost insulators assist the

* H. W. BUCK. "The Use of Aluminium as a Conductor." *Transactions of the International Electrical Congress*, St. Louis, 1904.

* *Journal I.E.E.*, vol. 49, p. 262, 1912.

Mr. Lustgarten. flashing-over, whereas the drops of water fall clear of the insulators when in the horizontal straining position. Photographs of spark discharges preceding flashing-over verify this statement.

I wish to endorse the view taken by the author as to horn arresters. The discharges across these are very liable to produce oscillations, which passing to the line may cause arcing over at an insulator, or maintain arcing at an insulator if it originally caused the arrester to act. Oscillations may also be produced on the transformer side. The ohmic resistance of the line is depended upon to damp out the oscillations, but in some stations in Switzerland and Italy which I visited last year I noticed that batteries of Moscicki condensers were used to absorb high-frequency surges. The slides show those in use at Beznau station on the Beznau-Löntsch transmission line at 25 and 40 kilovolts, the horn arrester having been discarded. Additional choke coils were required. A condenser has the advantage that for the same terminal pressure it will allow a greater current to pass the higher is the frequency of the oscillation. In Continental hydro-electric plants charges insufficient to cause arcing are prevented from accumulating or wandering on the line by the use of water-dropping devices which give the charges a free path to earth.

Mr Hollingsworth. Mr. E. M. HOLLINGSWORTH: I quite agree with the author that in industrial districts it is advisable to use poles of wood, provided, of course, that every care is given to their selection and treatment. In connection with one of our pole lines, on account of increasing the number of conductors we had a short time ago to replace several poles which were planted 12 years ago. We found all these wood poles to be in as good a condition as on the day when they were put in. As pointed out by Mr. Taite, poles and cross-arms of wood also give the advantage of a greater insulation resistance. We have had a similar experience of the burning of a cross-arm by a conductor without interfering in any way with the supply. As to corner poles, it is my experience that properly constructed A-poles are more reliable than H-poles; in fact I have found it necessary in several instances to replace H-poles with A-poles. With reference to line conductors, we have had short lengths of aluminium conductors under observation for the last 5 years, with the result that I have recently erected a considerable length of bare, stranded aluminium cable, consisting of 37 strands of 0·152 in. diameter, equal to a sectional area of 0·66 sq. in. We have used mechanical clips for the last 12 years, and they have proved quite satisfactory. I consider the triangular guard, as illustrated on page 191, will find favour with many engineers, especially for low-tension work. We have adopted this system of guarding in connection with a line supplying a 400-volt three-phase four-wire distribution; and in order to comply with the Board of Trade Regulation as to earthing at one point only, each triangular guard is connected to the fourth or neutral wire, but is insulated from each pole.

Mr. Medlyn. Mr. W. J. MEDLYN: I agree with the author that the wayleave powers possessed by the Postmaster-General could be extended with advantage, having regard to the insistent public demands for the extension of the telephone and telegraph systems, and especially in those cases where new services are required at short notice. Personally I am glad to be able to disagree with the statement that the powers conferred under the various Telegraph Acts are "almost useless." Some road authorities are not so helpful in the matter of wayleaves as they might be; but others recognize the public convenience represented by the telephone and telegraph services, and co-operate with the Department by conferring ready facilities for the extension of the system. The value of the Telegraph Acts depends to a considerable extent on the measure of assistance and co-operation which the Post Office receives from the highway authorities. The author appears to press for additional powers for an increase in the number of overhead high-tension transmission lines in urban districts; but the reason for this is not quite clear. The table given on page 178 shows the difference in cost between underground and overhead construction, but presumably the overhead figures apply generally to a rural district. In an urban district, owing to the presence of buildings and other obstructions, the cost of construction would be considerably increased, while owing to the presence of numerous telegraph, telephone, and tramway trolley wires, the guarding arrangements and protective devices would probably be complicated and costly. The author points out that annual charges in respect of overhead lines are greater proportionately than for underground cables, and there seems little doubt that this difference in favour of underground work would be accentuated in thickly populated areas. A statement showing the comparative annual charges on overhead and underground systems respectively would have been interesting. At one time the erection of overhead power wires in cities in the United States and Canada appears to have been greatly overdone, as a consequence of which numerous fires and fatal accidents resulted. In 1907 the American Bureau of the National Board of Underwriters furnished information to the effect that in the United States between 10th January and 19th April of that year—a period of just over three months—21 fires were caused by high-tension lines falling on telephone and electric light wires. About the same time public attention was directed to a number of disastrous fires caused by the general use of overhead power wires in Montreal City, as a result of which it was recommended that the wires should be placed underground. In June, 1908, an American journal called attention to the serious results of intermingling high-voltage electric light and power wires with telephone wires "in most cities and towns," as a result of which telephone linemen and repair men were frequently killed or injured by coming in contact with the high-tension circuits. The Board of Trade is hardly likely to agree to the copying of American practice in this respect, and of course I do not think the author had such an object in view in his brief remarks about the extension of powers within urban districts.

Factors of safety (page 179).—The author appears to assume that in the Post Office a factor of safety of 8 for poles and 4 for wires is observed in all circumstances. As a matter of fact the factor of safety is increased in exposed localities, whilst in sheltered positions the figures may be somewhat reduced. In some places the Post Office lines are liable to damage from sleet storms. No matter what the diameter of the wire may be, the gradually freezing sleet sometimes attains a diameter of 2 or 3 in. The

added weight (sometimes combined with wind effects) generally results in the wires breaking, and frequently the poles. In the *Post Office Electrical Engineers' Journal* of April, 1910,* particulars are given of a breakdown caused by a sleet storm in the north-eastern district, which show that pieces of ice taken from copper wires weighing 100 lb. per mile were found to measure over 2 in. in diameter and weighed 12 oz. per foot. This would give a weight of about $1\frac{1}{2}$ cwt. in a 66-yard span, or 3 tons in a span of 45 wires. So far as the Post Office is concerned, having regard to the frequency and extent of breakdowns of this character, it would not be economical to adopt a factor of safety that would prevent their occurence. In the case of power transmission lines, the difficulties arising from snowstorms are probably not so great as in the case of the Post Office lines, owing to the smaller number of wires carried and the greater diameter of the conductors. I do not think the accumulations of frozen sleet are as a rule much greater on a thick wire than on a thin one. Where the safety factor is provided for by means of metal stays subject to corrosion, due account should of course be taken of the atmospheric conditions. In many places in Lancashire galvanized iron or steel wire has a very short life, and frequent renewals are necessary to maintain the original strength of materials. In some places bronze and copper wires also become weakened by corrosion in a comparatively short time. The corrosive effects are as a rule more troublesome in urban districts than in the open country.

Telephone and pilot circuits (page 189).—Perhaps it may not be out of place to issue a warning note on the subject of telephone transmission. The standard of transmission aimed at by the Post Office for communication between any two subscribers is such as would be obtained in speaking over a distance of 25 miles through copper conductors weighing 20 lb. per mile, insulated with paper strip in lead-covered cables. With selected telephones and expert users in quiet surroundings, conversation could be maintained on such a circuit rather more than 40 miles in length. If the conductors are covered by a solid insulator such as gutta-percha or indiarubber, the transmission distance is very considerably reduced as compared with paper insulation, which provides an air space round the conductors. The author suggests that solid insulation might be used up to a distance of 40 miles; but under such conditions speech is not likely to be satisfactory, especially if conversation has to be carried on in close proximity to noisy machinery. A case bearing on this point came under my notice some few years ago where an important power company laid down an extensive underground transmission scheme between a number of towns. Telephone conductors were included in the same cable with a view to providing a complete system of telephonic inter-communication between all the stations for the purpose of controlling the power equipment; but unfortunately on completion of the work the use of the telephone conductors in the manner intended was found quite impracticable owing to the low grade of transmission.

Transposition of telephone wires.—The termination of two wires on a single insulator, as shown in Fig. 14, is open to the objection that dirt and spiders' webs are liable to cause partial contacts, while even with comparatively clean insulators the surface leakage in wet weather would be considerable, tending to interfere with the ringing as well as with the speaking efficiency of the circuit. In the Post Office it is the practice to terminate wires on separate insulators where transposition is necessary. The transposition method of running telephone wires is satisfactory where only one or two pairs are concerned; but where the lines are numerous the transposition arrangements which are necessary to prevent cross-talk between the pairs become very complicated. The rotary method referred to by the author is used in the Post Office.

Mr. Medlyn

Guarding of conductors (page 191).—The important question of guarding and protective devices offers a wide field for discussion, upon which I do not propose to enter. For those who are specially interested in this matter from the Post Office point of view, I cannot do better than recommend the perusal of a paper read by Mr. Bartholomew before the Metropolitan Centre of the Institution of Post Office Engineers in December, 1908. This paper deals with the subject very comprehensively, although in some respects it may not now be quite up to date. Copies of the paper are obtainable from the Librarian in the Engineer-in-Chief's office.

Mr. Paton.

Mr. J. D. PATON: Several speakers have emphasized the necessity of considering the economics of the case. It is well known that an aluminium line will transmit the same amount of power over the same distance and with the same number of watts loss as will a copper line of double the weight. Taking copper at £60 and aluminium at £85 per ton, it therefore means that two tons of copper at £60 are equivalent to one ton of aluminum at £85. Other speakers have mentioned the additional cost due to larger poles having to be used. The actual facts prove that on an average the cost of the poles for an aluminum line is 15 per cent higher than that of the poles which would be required for a copper line. This extra cost of the poles, however, is more than offset by the saving in the cost of the wire. The economy of aluminium is therefore established. Also, in view of its higher efficiency and the increased economy, I do not think even the most æsthetic engineer would raise a very serious objection to the greater sag of an aluminium line except when a copper line is in close proximity to it. As to scrap values, it may be of interest to members to know that in this neighbourhood aluminium has been purchased at a certain price and subsequently sold at a higher price. In modern lines stranded conductors are used for aerial transmission, and I might point out that although an aluminium transmission line might have to be taken down, the same strands are equally available for reconstruction into ordinary industrial cables. Modern developments have so established the purity of aluminium that corrosive effects can be practically disregarded. Looking into the future with regard to the possible developments of electrical engineering, the universal application of electrical power can only be effected by economy and efficient methods of distribution; and the final solution of this problem and the key of the position will be found in aluminium.

(*Communicated*): In his reply at the meeting Mr. Welbourn mentioned a case where copper had been bought for a certain price and resold with advantage to the customer after many years' use. He stated that the differ-

* T. B. JOHNSON. "A Record Breakdown." *Post Office Electrical Engineers' Journal*, vol. 3, p. 25, 1910–11.

Mr. Paton. ence between the value of the ordinary ingot and that of the scrap material was £6 per ton for copper and £20 per ton for aluminium. This would give the primary impression that there was a difference of £14 in favour of copper; but we must remember that in any scheme where aluminium is employed, only half the weight of metal would be necessary compared with a copper line under the same operating conditions. It must therefore be realized that the above £20 must be divided by 2 in order to give a true comparison, and the difference would become £4 instead of £14 if the aluminium had to be realized in the scrap market. As a matter of fact the loss likely to be incurred should a sale at scrap prices be necessary will almost be recouped not only by this decrement in the original price but also by the saving in the annual interest due to the lower first cost of aluminium lines.

Mr. Richards. Mr. A. F. W. RICHARDS: With regard to the table on page 178, it is of course true, as the author says, that the working pressure has little influence on the first cost of an overhead line, mechanical problems being far the more costly to overcome. At the same time I scarcely understand how the author makes out the cost of an 11,000-volt line as being equal to that of a 20,000-volt line. On page 185, he recommends a 3 ft. spacing for 20,000-volt and 2 ft. 6 in. for 11,000-volt lines, and in the specification given in Appendix XII he suggests a considerably severer test for the insulators. Surely these considerations must increase the cost of the line, even though it may be only to a trifling extent. The author no doubt intends that his comparison of the cost of underground cables and overhead lines should only be very approximate, but I think he should have made this clearer. The remarks of Mr. Taite and of Mr. Watson show how the cost may vary in practically the same neighbourhood. I have known of cases where owing to exceptional circumstances an overhead line would have been practically as expensive as an underground cable; for example, where the line would have to be erected alongside a public footpath and would therefore have to be guarded throughout its length, whilst the cable could be laid in the cheapest manner possible as the excavation and reinstatement were of the simplest description. I agree with the author that the possibility of using aluminiun should not be passed over without careful consideration when the cost is comparable with that of a copper line, after of course taking into consideration the increased sag and therefore spacing, which would necessitate longer poles and cross-arms. I think it has been clearly demonstrated that such a favourable comparison in cost cannot be made on lines of less than 0·1 sq. in. sectional area (copper). Such a size of line for high-pressure working is a large one, and therefore I am of the opinion that aluminium will not come for the present into general use for long high-tension transmission lines. The author recommends what I consider to be the only satisfactory method of jointing aluminium, *i.e.* butt-welding; in my opinion it is the difficulty of satisfactorily jointing in any other way within a reasonably small compass which has prevented the extended use of insulated aluminium cables.

Line clips.—I cannot agree with the author's statement (3) at the top of page 187. Since seeing an advance copy of this paper I have had an opportunity of examining a large number of clips erected nearly two years ago on a 0·15 sq. in. stranded copper line. Several hundred rigid-type clips are used on this line, and a careful examination was made of 72 of these; in no single instance was there the slightest perceptible sign of the glazing being chipped or chafed by the copper stirrup clip. A minute inspection was made through a magnifying glass for crystallization of the metal of the clamps or conductors, but there was no trace of this. I may say that these clips were delivered in bulk and no trouble was taken to fit to individual insulators. For such heavy lines as this I consider that the rigid clamp is the best method of tying up the conductors. The "Elder" suspender is certainly a good way of getting over the trouble of longitudinal movement of slings supporting insulated cables, but I do not quite like the retention of the old eyelet, which sooner or later pulls through the leather thong. The type which I prefer is of the hook and wedge pattern, with a far broader seating for the cable itself; this broad seating, which consists of a lead former braided with served jute, prevents the cable from slipping through, whilst allowing the hook to slide along the suspension wire. This is of great service in erection since cable can be hauled into position by men stationed at one pole whilst the suspenders are placed on the cable and suspension wire by a man at the next pole. There is no need to pay out the cable first and then to lift it into position and adjust the suspenders in the somewhat hazardous manner depicted on one of the slides which Mr. Welbourn has shown.

Guarding.—This is one of the most difficult problems in overhead line work. On circuits where some protective device such as the Merz-Hunter is installed, I think that the Board of Trade might allow lines to be left unguarded along country roads. For small lines the guard illustrated on page 191 appears very simple and effective. I should certainly like to adopt it on small low-tension lines if Mr. Trotter has put forward the design for anybody to use without licence.

The only other point that I should like to mention is in connection with the useful tables which are published at the end of the paper. I think the author should give the formula and an example for use with the table in Appendix IV. Its use is quite clear when properly explained, but he has left too much for us to think out for ourselves. In Appendix III I venture to criticize the advisability of giving the ohmic resistance of two wires; that is, the columns are headed "Per Mile of Line" and "Per 1,000 Yards of Line," whereas they mean (it is certainly explained in Note (*a*), but there is no corresponding reference letter on the table itself) "Per 2 Miles of Wire" and "Per 2,000 Yards of Wire." Now nearly all lines consist of at least three wires, so the expression "Per Mile of Line" has no real significance except for a single-phase line. A multiplier of 2 in the formula would overcome this and prevent mistakes.

Mr. Malcolm. Mr. G. W. MALCOLM (*communicated*): As we are operating one of the latest examples of high-tension overhead transmission lines, the paper is especially interesting. It may be of interest to mention that this line of the Mersey Power Company has been in operation for just over 18 months, transmitting alternating current at a pressure of 6,000 volts over a distance of 8 miles, and we have had no trouble whatever, in spite of some very severe storms. Although we did not have any trouble with

local authorities or others with regard to wayleaves, we quite agree with the author's suggestions that some curtailment of their power is advisable.

Mr. B. WELBOURN (*in reply*): This discussion has proved very interesting because of the number of really useful points which have been brought forward. Some of them have been dealt with at other local section meetings, and to avoid repetition it is necessary to ask members to be good enough to read the replies made elsewhere.

Aluminium conductors have received much attention, but I fear that despite my partiality for the metal, I cannot altogether follow Mr. Paton in his enthusiastic advocacy of them. To my mind the question of using aluminium or copper can only be decided after weighing the advantages and disadvantages in each particular case and after most carefully comparing the over-all costs of each. There is no real difficulty in connecting copper to aluminium, but the joint must be protected from air and moisture unless it is in a dry place. In reply to Mr. Watson, the scrap values of clean electrolytic copper and aluminium are approximately £6 and £20 per ton respectively below the current market prices of wire bars. I am afraid that Mr. Paton has been misinformed as to the possibility of using discarded aluminium strands from an aerial line for insulated cable-making. Because of the surface scale such strands would have to be melted down into bars and redrawn into clean wire in most cases. Apart from this, it is usual, for well-known reasons, to employ a larger number of wires in an insulated cable than in an overhead conductor. Aluminium will have a better chance when the production of the metal increases and there is more of it available for electrical (as apart from mechanical) work. The price will then perhaps be lowered. Copper lines of 0·10 sq. in. and under are at present usually cheaper than the equivalent aluminium lines.

In regard to line protection against lightning and other disturbances, I think it is correct to say that the North Wales Power Company's lines have been very free from trouble since the adoption of the Moscicki condenser. Last year I examined an overhead line in the Balkans which had been much troubled with lightning. This was cured by the installation of these condensers and air-cored choking coils of iron. The use of paper-insulated lead-sheathed cables for connecting up overhead lines at both ends has much the same effect as the Moscicki condenser in dealing with high-frequency oscillations. There is no real difficulty in connecting up an overhead line in this way, and I think I have seen it done on Mr. Taite's own lines. The chief difficulty has been with the terminal boxes between the cable and the line. Boxes using vertical insulators on the top are being superseded with very satisfactory results by boxes of the inverted type. In these boxes the insulated cable can easily be sealed in with waterproof compound and the leading-in insulators can be arranged for renewal from outside in the event of breakage.

I am glad to see that Mr. Watson agrees with me about the material to be used for the longitudinal earth-wire. Its position on a line must be determined by the conditions to be met. When used below the power wires it provides a ready means of supporting a telephone or pilot cable.

One useful point that has been brought out in these discussions is the liability to trouble on lines erected in the neighbourhood of high-powered wireless-telegraph stations, and that immunity from trouble can only be secured by keeping a line at least a mile from such a station and at right angles to the station antennæ. Underground cables should be used at any less distance than this.

Mr. Hollingsworth has raised a point, which has not been discussed in the paper, in regard to transplanting creosoted wood poles. I think there is considerable evidence to show that creosoted poles have a life of fully 35 years if planted soon after creosoting and if left undisturbed. Removed poles are often found apparently as good as new, but they sometimes rot within two or three years if used again. The reason appears to be that there is no free creosote to form a fresh germicide area around the pole below the ground. I do not know whether anybody has tried pouring creosote into the holes around transplanted poles, but it would seem to be worth a trial.

The triangular guard is being developed in a variety of forms for both high-tension and low-tension work, and further information about it is given in a paper which its designer—Mr. A. P. Trotter—read before the Institution of Post Office Electrical Engineers in London on 20th January, 1914. I may say that anybody is free to use the design. Mr. Trotter's paper only deals with low and medium-pressure work, but it, and the discussion on it, contain a large amount of exceedingly useful information and make much clearer the attitude of the General Post Office and the Board of Trade on the question of guarding.

It seems to me to be questionable practice to rely on wood arms as secondary insulation. I know that it is a controversial point whether wood or metal arms should be used, and some engineers seem to put the question into the same category as "Earthed *v.* Unearthed Neutrals" and "Lead-sheathed *v.* Bitumen-sheathed Cables." Surely it is best, when a fault comes, to have to deal with it promptly and to be done with it!

Mr. Lustgarten has mentioned several useful points and supports my views on horn arresters, as several speakers have done elsewhere. I am surprised to learn that there is at the present time any doubt as to the relation between wind velocity and pressure. The *Encyclopædia Britannica* gives the following table, which is, I think, the one commonly accepted and worked to:—

	Velocity in miles per hour	Pressure in lb. per sq. foot
Calm	0	0
Light breeze	14	1
Strong "	42	9
Strong gale	70	25
Hurricane	84	36

I think it is necessary to distinguish between gusts of wind and steady pressure. Experience shows that the above pressures are not maintained all along a line, or else lines might be wrecked frequently without any snow accumulations. Trouble from wind usually comes on short spans on which the wind pressure has concentrated, and not on long spans. On lines crossing ravines and country where wind concentration may be expected, it is advisable not to erect any conductor of less than 0·10 sq. in. section. Mr. Lustgarten's suggestion about testing insulators with high-frequency pressures as well as with normal-frequency pressures is one which will, I hope,

Mr. Welbourn. receive attention from the insulator makers and from consulting engineers. The same subject has been raised by Mr. Burnand in the Yorkshire Local Section discussion.*

I am sorry that I have already dealt with so many of Mr. Medlyn's points elsewhere, but I may explain again that my remarks on wayleaves refer to private wayleaves for "work across country." The information in regard to corrosion is very valuable, backed as it is by so much Post Office experience. It confirms the remark which I made while reading the paper, that in urban districts it would be an improvement to coat all galvanized wire with a preservative compound immediately after erection and not to confine the extra protection to nozzles only.

I am glad of the opportunity of dealing further with the question of telephone transmission, as it is not possible to elaborate every point in a paper which must be kept within reasonable limits of length. Working on Sir William Preece's formula, it would be necessary to use copper conductors weighing 40 lb. per mile with solid paper insulation to have satisfactory transmission over a line 40 miles long, while 20-lb. conductors would be sufficient on a 30-mile line. Of course this assumes that the wires are laid up in pairs in accordance with the best modern practice. I have had some experience, similar to that mentioned by Mr. Medlyn, of the difficulty of telephone working on a big cable network. The difficulties can be and have been overcome on modern cable systems, and there are now several successful telephone lines in use. The solution of the problem is one that requires a good deal of experience.

I have met the difficulty of Mr. Richards and other engineers in regard to Appendices III and IV by working out the two examples which appear at the end of my reply to the London discussion. In regard to rigid clamps, I am still of opinion that they are undesirable ; the two instances given in my paper, and also the experience of rigid supports on tramway trolley wires, confirm this. In addition to this, the rigid clamp is an expensive article and can be readily displaced at much less cost by a flexible wire binder such as is illustrated in Fig. 8. Mr. Richards and another speaker misunderstood the lantern slide showing the conversion of the suspension of a telephone cable. Usually the cable may be attached to the suspender cable while on the ground by means of the Elder hangers and then the combination is strung up. I paid close attention to the cable sling described by Mr. Richards. I think his lantern slides showed quite clearly that the hanger is only used—and can only be used—for slinging up cables protected by jute along which the hanger would not slip, and that it was quite unsuitable for use with a small-diameter plain lead-sheathed telephone cable. I would refer those who are further interested in this question to the remarks by Mr. Vernier in the discussion before the Newcastle Local Section.*

* See page 316.

* See page 306.

Yorkshire Local Section, 14th January, 1914.

Mr. Johnson. Mr. T. B. Johnson : The author states (page 179) that "an **A**-pole is about $4\frac{1}{2}$ times as strong as a single pole comprising one of the legs," and that "an **H**-pole without trussing tackle is about $3\frac{1}{4}$ times as strong as a single pole comprising one of its legs." The use of **A**- and **H**-poles respectively is of great importance, and I should be glad if the author would say whether the figures in regard to **H**-poles have been obtained by actual experiment or by calculation. In the case of **A**-poles the figures have presumably been obtained from the paper contributed by Mr. Wade to the Institution in 1907.† In view of the fact that **A**-poles are stronger as well as cheaper than **H**-poles, and that the wind pressure on them is smaller, it would be interesting to learn why **H**-poles are being used extensively, especially at angles (see page 184). In this connection it might be pointed out that the **H**-poles shown in the paper bear a strong resemblance to those given in the Post Office Technical Instructions, No. XIII. The Post Office practice, however, is largely governed by the fact that it is necessary to provide for a large number of wires in a square. This requirement does not exist in the case of poles for power wires. The flexible telephone binder illustrated in Fig. 11 is suitable only for light bronze wires. Copper wires, of say 100-lb. gauge, should be bound in by means of flattened copper tapes and binders, the tapes preventing injury to the line wire. I think Fig. 14 should be amended so as to show two pairs of insulators. If wires were "made off" on the same insulator, the losses due to leakage in wet or foggy weather would be very considerable, especially in smoky districts ; and as the circuits are already subject to disturbance owing to the proximity of the power wires, it is desirable that leakage should be prevented as far as possible. I should be glad if the author would state the highest voltage in connection with which the triangular guards illustrated in Fig. 16 have been used, and also whether they are intended for use on high-tension or medium-pressure lines. Can he also say whether they have been used at crossings over railways, roads, or Post Office wires ? A glance at Fig. 17 will show how desirable it is to avoid combination poles as far as possible. The Postmaster-General has expressed his willingness to place his wires underground (at the cost of the power undertakers) in those cases where only local wires are affected. Would it not be possible to come to an arrangement for the Post Office wires to be placed underground in those cases where telegraph or short-distance telephone wires are affected, and for the power wires to be placed underground where the Post Office poles carry long-distance trunk circuits and it is necessary to retain a high "speaking efficiency" ? The difficulties which faced power engineers a few years ago in placing their wires underground seem to have been surmounted to a considerable extent, and the use of underground power mains now appears to be less objectionable and costly than the erection of elaborate joint poles.

Mr. Lang. Mr. W. Lang : I should like to know whether in view of the steady increase in the use of overhead lines any steps have been taken to ensure the least possible obstruction in open country. That is especially important in view of

* See page 316.

† C. Wade. "The Use of Wooden Poles for Overhead Power Transmission." *Journal I.E.E.*, vol. 39, p. 304, 1907

ang. possible future developments as portrayed by Dr. Ferranti in connection with the transmission of power. What has been done up to the present is the merest bagatelle compared with what would be required if anything approaching Dr. Ferranti's forecast were attained; and this would necessarily mean a careful lay-out of the overhead network so as to prevent the country's assuming the appearance of a gigantic spider's web. Then again, the construction shown in Fig. 17 on page 192 may be a sound piece of engineering work, but it is by no means beautiful from any other point of view; especially when one considers that the same end could be reached by going underground at such a point.

torr. Mr. J. E. STORR: I think the author's opening remarks with regard to the relative costs of overhead line construction and cable work for voltages up to 3,000 should not be passed without challenge. I cannot agree that cables are even generally cheaper than overhead lines up to pressures of 3,000 volts; and to confine the use of overhead lines to higher pressures would be most detrimental to the cheap supply of energy in districts where an extra-high-tension supply is not warranted by circumstances. I have in mind lines operating at a pressure of 2,000 volts serving as distributors from extra-high-tension sub-stations where cables would be prohibitively costly. As to the factor of safety on the conductors, the author holds that the present factors are necessary for power circuits, and suggests that the wires of the Postmaster-General are not on the same footing as power wires, as the danger to the public due to falling wires is not the same. This may be so in many places, but with the extensive use of aerial conductors for traction and power distribution there is a very real danger from contact between telephone and power wires. The factor of safety on the Post Office wires should be increased if the present factors for power wires are to be retained. As the matter stands to-day, the guardings have to be erected about power lines to ensure that not only power wires cannot fall on the Post Office circuits, but that broken telephone and telegraph wires cannot foul the power lines when the former get adrift.

In the description of typical overhead lines the spacing of the conductors is given as 5 ft. for a pressure of 20,000 volts and 4 ft. for 11,000 volts. These figures appear to be unnecessarily high, and must involve an annual charge for line losses which materially reduces the advantage of a saving in capital expenditure by the use of overhead lines. The figures given at the bottom of page 185 are quite sufficient; in fact there are a number of 11,000-volt lines which are working quite satisfactorily at 2 ft. 2 in. centres. I think there is a tendency to extravagance in some designs, and the factors of safety adopted are altogether unnecessary. This is perhaps due in some measure to the wide difference in cost between aerial and cable work; but the tendency must be checked or else the advantages of reduced distribution costs will be much less than they might be. At the same time, first cost must not be the pre-eminent consideration, as absolute reliability of service is of paramount importance and must have first consideration. The author recommends H-poles for angles, but I think that A-poles should be given preference on account of the greater stability of the latter. The design of the pole equipment has to have full consideration when the type of pole is considered, but I think the very effective strutting of one pole to the other and the lock obtained by the oak key gives the A-pole a strength which cannot be obtained by any amount of cross ironwork, tie-bolts, etc. Unless very deep gains are cut to receive the channel arms and extra heavy brace-work is used, the small bearing surfaces allow racking of the H-poles when the latter are used at angles, and an unstable structure is the result. Mr. Storr.

Under the heading "Insulator Pins and Fixing," no mention is made of the method of fixing insulators by metal thimbles. These thimbles are threaded inside to Whitworth standards and cemented into the insulators by the insulator manufacturers when the insulator parts are set together. The thimble is thus fixed by expert workers and a good job is ensured, and all that is necessary during erection is to screw the insulator on to the pin —thus skilled labour as required for cementing in pins, and more especially for oiled twine fixing, is unnecessary. A great advantage due to metal thimbles is the easy removal of a damaged insulator, an operation which can be performed in any weather in a few minutes. I think in cement fixing it is difficult to set insulators to stand upright on the pins. In the case of twine-wrapped pins unless the packing is done very effectively the cushion effect is lost, and small movements of the insulator on the pin, particularly at angles, soon burst the insulator due to the unequal strains.

Under "Guarding of Conductors," the author mentions an earthing bracket fixed only 8 in. away from the conductor and 12 in. out from the insulator. Is the distance out from the insulator adequate? Would not a line falling clear 12 in. before touching the bracket; also 8 in. from wire to bracket appears to be more of a menace than security, as large birds would no doubt set up an "earth" if they got on the bracket.

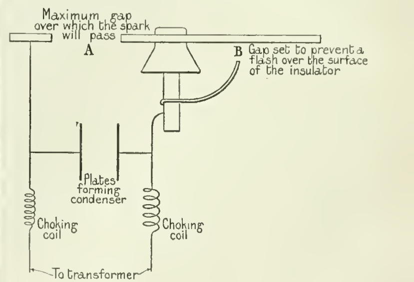
With regard to the alternation of solid or stranded conductors, where any doubt exists as to the corrosive effect of the atmosphere on conductors, stranded wires should be avoided owing to the percolation of fumes into the interior of the lines; to some extent the effect of such fumes is reduced externally by rain washing, etc., and on examination a false sense of security is obtained. If a 4/0 S.W.G. wire is not large enough I should prefer to run more than one circuit to avoid stranded conductors of any metal under doubtful circumstances. I should like to ask the author if he has observed any great difference between the snow and ice loading of conductors in the case of stranded and solid conductors. In conclusion I endorse all that the author has said with regard to the difficulties in connection with wayleaves, and I think the necessary steps should be taken by this Institution, or by a combination of the parties most concerned in this matter, to obtain greater freedom in wayleaves and consents. If it is only possible to establish Courts as on the Continent to arbitrate promptly in cases of difficulty, it will be a great advancement.

Mr. W. H. WRAITH: In connection with the author's remarks on page 190 with regard to telephones and bare telephone wires, I should like to point out that there is a considerable mileage of bare telephone wire fixed on the power poles in this district, and that instead of using high-tension telephones, well-designed protective gear is connected on the line side of the 1–1 transformer, thus effectually earthing the line in the case of a short-circuit Mr. Wraith.

Mr. Wraith. from the power lines. This not only protects anybody using the telephone but also protects the instrument itself, thus taking the element of danger one complete step further away from the operator and allowing ordinary long-distance loud-speaking telephones to be used in every case.

Mr. Burnand. Mr. W. E. BURNAND: In the Board of Trade Regulations the stress to which a wire is subjected due to wind and ice is taken as proportional to the diameter of the wire. It is well known in aeronautics that with a small wire the stress due to wind is by no means proportional to the diameter, being much larger in proportion on small wires; and also that if the wire is in a state of vibration the stress is greatly increased. Further, the loading due to ice is not at all proportional to the diameter of the wire; in fact the diameter of the wire has little influence on the thickness of the ice that is formed. As the stresses which cause wires to break down are almost invariably due to a combination of ice and wind, it follows that any calculation based on the assumption that the stress is proportional to the diameter of the wire is by no means in accordance with the facts, and that a small high-tension wire erected on this basis would be relatively much weaker than a large low-tension wire. Considering the relative stress on wires due to wind and ice together, it will be seen that instead of the actual factor of safety on an average power line being about double that on an ordinary telegraph line, as would appear from the Board of Trade constants, the factor of safety is actually more like 5 or 6 times that of the telegraph wire. Whilst this shows the impracticability of bringing the telegraph line to a point where it can withstand the severe conditions of wind and sleet that cause so much trouble, it also shows that the tendency would be to make with the further development of overhead distribution the heavy low-voltage line still stronger and the weak, light high-tension lines less safe than they ought to be. I think that a more accurate method would be to base a formula on accurately observed results on a wire of about ½ in. diameter, obtain the constant from this, and then calculate the permissible loadings for other sizes, assuming the stress to vary as the square root of the diameter instead of in direct proportion to the diameter. This should give approximately the same degree of safety throughout a fairly wide range of sizes of wire under the conditions which actually cause breakdowns.

Another point is with regard to high-tension insulators, which, although designed to flash over rather than puncture, do in service occasionally puncture, usually during a thunderstorm or when a high-frequency surge or sudden shock occurs due to a short-circuit or some other transient disturbance on the system. It is evident that there are at least two ways in which an insulator may break down, the first being analogous to a straight shear where the breakdown occurs simultaneously throughout the substance of the insulator, and the second a progressive disruptive effect which travels through the insulator somewhat in the manner in which a crack caused by a sharp rap travels through a piece of glass. The first occurs at the ordinary frequency, and the second is due to sharp shocks such as may be caused by the high-frequency disturbances just referred to. Some interesting experiments on this subject have been carried out by Messrs. L. E. Imlay and P. H. Thomas.* It was found that the puncture strength in the case of a high frequency had little relation to the strength on normal frequency; for instance, an insulator that withstood without puncturing under oil a pressure of 250,000 volts at 60 cycles, punctured at a pressure of 100,000 volts, the frequency being estimated at 1 million —a frequency quite comparable with the jerk due to a lightning discharge in the vicinity of the wire. These experiments, and the fact that insulators actually puncture in service in preference to flashing over, show that the tests as outlined in the appendix to the paper still leave in many cases a weak spot untested. I think the tests outlined should be supplemented by one designed to test the above point, since it is quite certain that insulators have to stand in service these sudden shocks, and should be designed accordingly. It is quite a simple matter to make such a test; all that is required is a small length of conductor fastened to the insulators in the ordinary way, and to discharge on to this short length from the testing transformer over a gap of a length that the testing pressure can just jump. Under these conditions there is of course a very sudden jerk at the instant that the spark occurs. This stress is reversed just as rapidly when the wave arrives at the reverse peak, and under these conditions it is theoretically possible to get twice the maximum value of the peak on the insulator, *i.e.* with a testing pressure of 70,000 volts (R.M.S. value) it is theoretically possible to get a pressure on the short length of conductor of about 200,000 volts; but this, of course, neglects all losses and the resistance in circuit, and there is no doubt that the actual value is much less. It might be thought that even though this pressure is considerably less than the theoretical maximum the increase of pressure was the cause of breakdown under this test; but this is hardly the case, since it is the relation between the puncture and flash-over values, which ratio is evidently very different under these conditions from that under the conditions of normal frequency. The diagram herewith shows the arrangement for making the test on very high voltages. The arrangement of choking coils and condenser is designed to protect the transformer end-turns from the heavy shocks that occur under these conditions, and is substantially the same in principle as that adapted by Messrs. Imlay and Thomas, except that those experimenters omitted the choking coil



* *Electrical World*, vol. 60, p. 1355, 1912.

from the earthed side of the transformer—which I think is not justified, as the pressure between the end-turns is just the same on the earthed as on the high-tension side of the transformer. For testing pressures below 50,000 volts it is doubtful if the condensers and choking coils are at all necessary for protecting the transformer, a simple resistance in the primary of the transformer so as to limit the current when the spark occurs being sufficient; but this of course depends to some extent on the transformer itself, since different transformers vary in the relative strength and capacity of the end-turn insulation.

Mr. H. E. YERBURY: The equipment of high-tension overhead lines has almost reached the standardized stage, and as many power distribution schemes are only commercially possible with overhead transmission the greatest obstacle appears to be the granting of wayleaves. I am inclined to think that greater progress would be made in that matter if æsthetic considerations were not divorced from strict utilitarianism. As mentioned by the author, public roads appear to be suitable for the erection of poles, but I think that perhaps adjoining railway track would in many cases be preferable, assuming of course that other wires would not be seriously influenced by these high-tension lines. It would undoubtedly be most satisfactory to aviators if it could be arranged for all extra-high-tension lines to be erected on or adjoining main roads and railways, leaving as far as possible the open country for either voluntary or involuntary descents. As reinforced concrete poles are not mentioned in the paper, I should be glad if the author would give his views with regard to these, as I have seen many designs of such poles on the Continent and should like to know what are the disadvantages apart from their weight. I cannot agree with the author that the deterioration and maintenance of steel tramway poles is high, for I have recently had occasion to remove many centre tramway poles after a life of 12 to 13 years, and they were found to be practically as good as new poles. It should be mentioned that all the poles were fitted with bases, which I think adds greatly to their life, as the point of corrosion is generally found at the surface of the road. The average cost of painting was from 5s. to 6s. per pole; these poles were painted every three years, and the bases and collars were raised for that purpose. As atmospheric and other conditions in England are favourable compared with other countries, I think it is only a question of time when extra-high-tension lines of higher voltage will be run in country districts, but I believe underground cables will still hold their own in all cities and fair-sized towns. Judging by the overhead work which is to be seen in foreign towns, I feel thankful that we have a reasonable Board of Trade to regulate our schemes in this country. I heartily endorse the author's suggestion that representations should be made by our Institution to the Board of Trade on matters requiring revision, as is done by the Tramway Associations on matters relating to tramways.

Mr. E. V. PANNELL (*communicated*): Considered in connection with others which have been presented during the last few years, this paper affords evidence that overhead power transmission in England is now being treated as an everyday engineering problem and not as an undesirable and temporary makeshift. In agricultural districts I believe much could be done by way of selling electrical apparatus and energy to farmers. In Ontario, for example, electricity is distributed by overhead mains to the farms, where it is used for milking and threshing machines and is also beginning to displace steam for ploughs. Undoubtedly after manufacturing and mining districts have been supplied there is reason to believe that the agricultural communities will prove the next to be persuaded of the advantages of electricity supply. With reference to the author's remarks on steel poles at the foot of page 179, he surely does not mean to suggest that the formula given on page 180 represents the whole of the stress on the pole, and that no allowance need be made for wind and ice. This can only be neglected where the wires are of considerable size and θ is nearly 90 degrees. Possibly the factor of safety of 4 is meant to cover all the non-calculated stress; this would bring the design into line with the structures used in America, where all the stresses are worked out and a factor of safety of 2 or 3 is employed. The table in Appendix XI showing the maximum angle of swing of the wires is interesting but should not be looked upon as inflexible. For one thing, the wave front of a wind is not often a plane; the pressure will therefore vary throughout the span and the wire will not hang in the form of a catenary. This will cause ripples to be set up along the wire. Further, the direction of the wind often deviates from the horizontal, especially over ravines where an upward vertical gust is not uncommon and frequently gives trouble where insufficient spacing has been allowed. If the wind pressure has a downward component it will of course increase the sag, as it will be adding to the apparent weight of the wire.

I was interested in the author's suggestion that a 70 per cent yield-point should be specified for aluminium conductors. As a rider to this a standard method of test should be specified; for I have found tests on aluminium wire to give very varying results according to the method adopted. Short specimens of wire tested by the "point to point" method on a beam testing-machine certainly give a misleading value for the modulus of elasticity, the latter always appearing too low. It is surely time that the Engineering Standards Committee should give their attention to the formulation of a specification and tests of aluminium wires and cables. Further to this I most heartily second the author's proposal that a Transmission Lines Committee of the Institution should be appointed. Such a committee, working along similar lines to those of the National Electrical Light Association in America, could accomplish work of considerable value to all engineers and manufacturers associated with our industry.

Mr. B. WELBOURN (*in reply to the discussions before the Newcastle and Yorkshire Local Sections; communicated*): After each discussion I answered fully most of the points that were raised. Some of them had also been brought up at other meetings and have already been replied to; I hope members will therefore be good enough to look through the replies in the *Journal*.

Mr. Hunter, Mr. Storr, and Mr. Vernier have dealt with various aspects of the general comparison between the cost of cables and of overhead lines. Mr. Hunter and Mr. Vernier have raised a question of importance in regard to cable design which falls rather outside the scope of the paper. It is quite true that the Engineering Standards

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Committee's specifications for cables were prepared several years ago and before high-tension cable manufacture was so well understood, but no dielectric thicknesses have ever been standardized for alternating pressures above 11,000 volts. It is permissible to point out that the cable specifications of the Engineering Standards Committee are not obligatory on anybody, and it is open to any engineer to specify other dimensions for his cables; but it must always be borne in mind that any reduction in dielectric thickness also inevitably means a reduction of the factor of safety. Possibly the time is approaching when the Engineering Standards Committee can profitably undertake a revision of their cable specifications, because the conditions on modern systems are changing to the advantage of the cable manufacturers. For example, alternators with a sine curve can now be obtained, automatic balanced protective devices such as the Merz-Hunter and Merz-Price are coming into common use, and the design and quickness of operation of high-tension switchgear have been much improved. On modern supply systems working at pressures up to 11,000 volts it seems quite possible that dielectric thicknesses might be reduced; but I think it would be difficult to make out a good case for doing so on any alternating-current system supplied by plant of old design and having a bad wave-form. It may not be out of place to recall the fact that approximately one-half of the capital invested in the electric supply business in the United Kingdom has been spent in cables, and it is without doubt mainly due to their reliability that electricity supply has been able to obtain the confidence of the public. I am very interested in Mr. Hunter's theory as to the beneficial action of paper-insulated cables when used in conjunction with overhead lines. Apparently he thinks that they are equal to Moscicki condensers in their ability to relieve the system of high-frequency disturbances of the order of, say, 100,000 per second, and much superior to them when frequencies of the order of 500 to 1,000 per second have to be dealt with. There is much to be said for Mr. Hunter's view, but nobody yet knows what is the maximum loss in watts that can be permitted in the usual dielectrics without causing injury sooner or later. Heating of any dielectric is always objectionable, and how far it can be carried must be decided by future investigations.

Mr. Vernier's amplification of the particulars given in the paper of the Elder suspension system for lead-sheathed cables is most valuable and will be carefully noted by all those who are interested in this question. The discussions have shown that strong views are held for and against the use of bare telephone wires. Where they are used, I understand the Home Office is enforcing the use of some form of high-tension telephones. Money spent on apparatus which can be relied on to protect the operators under all circumstances is money well spent.

Mr. Johnson queried the advisability of using the arrangement shown in Fig. 14. It was intended to be diagrammatic, and I quite agree that in practice the leakage distance should be much longer than that indicated. This arrangement can be used in clean country districts; but where there is much coal-dust, etc., two pairs of insulators may be used for the transposition. The triangular guard illustrated in Fig. 16 was used on a 6,000-volt three-phase line across country quite near to London. With suitable additions it may be used for railway, road, and Post Office crossings. Fuller particulars of it are given in a paper read by Mr. A. P. Trotter before the Post Office Electrical Engineers in London on the 20th January, 1914, and I understand that it is also to be read again shortly in Leeds before a joint meeting of the Post Office Engineers and this Institution. I think most power engineers now prefer to cross Post Office trunk circuits by means of underground cables. It is usually cheaper and more sightly to do so than to arrange for combination poles, and it has been found, as pointed out by Mr. Hunter, that there are advantages in having some insulated cables in high-tension circuits. So far as I know, no thorough investigation has ever been made into the strength of H-poles with and without trussing tackle. The figure of $3\frac{1}{2}$ given for an H-pole is the result of calculation and much experience, but there are no reliable data as to the exact additional strength obtained by adding one or more sets of trussing tackle. I suggested to Mr. Wade at Leeds that he would confer a boon on the industry if he would carry his standard work on A-poles further and do the same for H-poles. H-poles are frequently employed at corners on transmission lines in order to preserve the spacing of the conductors. They are much more sightly than A-poles, which may have to be provided with specially long arms.

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Mr. Storr mentioned the earthing bracket on page 191. It has been found satisfactory in practice, but I think it is clear it should only be used on a high-tension line working with an unearthed neutral. In regard to the collection of snow, I think a stranded conductor will necessarily begin to gather it earlier than a solid one. This question is linked with the one which was raised by Mr. Vernier about the difference in behaviour between short and long spans, and it has been dealt with already in the Manchester discussion, as has also Mr. Burnand's valuable suggestion about testing insulators under high frequency.

I think Mr. Pannell has rather misunderstood the reference on page 179. (B) belongs to Section I. Section II deals with "stress on poles due to change in direction of wires," and applies both to wood and to steel poles. The probable loading of wires by snow and ice must of course be taken into account in calculating the stress on the poles, but in British practice it does not appear necessary to make further provision for ice and snow on the poles themselves. The factors of safety for wood and steel poles take care of this loading. The remarks on the varying behaviour of wind go to confirm the views expressed elsewhere that short spans are more affected by high winds than long spans are. I am sorry that Mr. Pannell was unable to be present at the reading of the paper as I dealt more fully with the question of the 70 per cent "limit of proportionality" or "elastic limit." This point is lower on the curve than the "yield point." The tests referred to have been made by a careful engineer with a Dennison testing machine on 5-in. and 6-in. specimens of aluminium, and the results obtained are remarkably consistent for the sizes of wires in the table on page 185. Subsequent tests on aluminium strand tend to show that the limit of proportionality on strand is rather higher than on single wires, and further investigation is being undertaken to settle this important point definitely. For the present I think a standard specification for aluminium could better be dealt

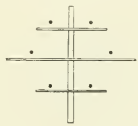
ourn. with by the suggested committee of this Institution than by the Engineering Standards Committee.

The discussions have brought out varying experiences with steel poles. Mr. Yerbury's results after 12 years' use of poles in Sheffield have been quite satisfactory, and presumably his tramway tubular poles are not made of high-tensile steel. Mr. Elliott's experiences agree with mine, and he is in no doubt that steel poles should be avoided whenever possible. It is always to be remembered that our climatic conditions are often unfavourable to steel, and I know of one important railway where even the steel rails have to be painted in order to prevent unduly rapid corrosion. In a humorous vein Mr. Ward has asked me for an estimate of the life of the steel towers at the River Blyth. My views on the general question of steel poles have not been disguised, but I think it would be impolitic to give a specific answer to his question. This is a particular case where I do not doubt the poles will receive special care and maintenance.

Mr. Elder has made a powerful appeal to designers and erectors to study the general appearance of overhead lines and to make them as little displeasing as possible to the eye. It is to be hoped that this will not pass unheeded, as there is certainly plenty of room for improvement. Wayleave difficulties are often responsible for a slovenly appearance. If these could be overcome and lines thus run straight instead of following nearly every fence, the gain in appearance would be immense. Mr. Elder's confirmation of the great need for studying details is timely. His own work on the suspension of lead-covered cables of small diameter has been of the greatest benefit, and has done much to make their use possible on overhead lines. Mr. Bridges and Mr. Gillott have given whole-hearted confirmation of this view. Mr. Beard's query is quite to the point. Lead-covered cables have many excellent features, but freedom from collection of snow is not one of them. In the slides which were shown most of the snow had already fallen from the insulated telephone cable. Mr. Welbourn.

I have much sympathy with Mr. Ward's suggestion that heavy terminal boxes should be allowed to rest on the ground during jointing instead of being placed aloft on terminal poles. It would facilitate the work and be much safer for the workmen, and I hope that engineers will specify that the work shall in future be done in this way.

In reply to Mr. Gregory, I prefer the arrangement of the conductors of a three-phase line in one horizontal plane to that in a vertical plane. There is certain evidence (which will probably be made public later) to show that the sum of the wind pressures on the horizontal wires is considerably less than that on the vertical wires. For duplicate-circuit lines an excellent arrangement of the wires is shown in the accompanying sketch.



Mr. Porter's experiences with telephones are very valuable; the only entirely satisfactory solution of his difficulties would appear to be to use high-tension telephones throughout.

INSTITUTION ANNOUNCEMENTS.

Lending Library.

The Lending Library Catalogue is issued with this number of the *Journal* to members residing in the United Kingdom.

Associate Membership Examination.

An examination will be held on Friday and Saturday, the 1st and 2nd May, at the Examination Hall of the Royal Colleges of Physicians and Surgeons, Queen-square, Bloomsbury, W.C. Should a sufficient number of candidates make application, arrangements will be made for the examination to be held concurrently in local centres.

Entry Forms, which must be returned not later than the 2nd March, may be obtained together with the Examination Regulations on application to the Secretary of the Institution.

Beit Scholarships for Scientific Research.

The second election of Fellows will take place on or about the 15th July, 1914. The Fellowships, of which not more than three will be awarded at this election, will be tenable at the Imperial College of Science and Technology, South Kensington, and will each be of the annual value of £150. The tenure of a Fellowship is for one year, but it may be extended by the Trustees for a further period not exceeding one year. Candidates must be under 25 years of age on the date of election. Applications will be received up to the 15th April, 1914, and must be made out on special forms, which, together with any other particulars in respect of the Fellowships, may be obtained, by letter only, addressed to The Rector, Imperial College of Science and Technology, South Kensington, London, S.W.

SUGGESTED METHODS OF IMPROVING THE TELEPHONE SERVICE.

By W. Aitken, Member.

(*Paper first received 20th June, and in final form 6th October,* 1913; *read before the* Newcastle Local Section *9th February,* 1914.)

Complaints by Public.

Grave complaints are being made regarding the efficiency of the telephone service. Whether these are justified or not it is rather difficult to say without a very careful study from the inside. The old National Telephone Company received a fair share of complaints and abuse, and the Post Office have taken that over—with perhaps something added to it—along with the plant and other effects of the Company.

The complaints are not very specific, but they may be tabulated thus :—

1. Failure to give service.
2. Charging for service that has not been given.
3. Mistakes in operating.
4. Operators incorrectly reporting lines engaged.
5. Premature severing of the connection.
6. General slackness on the part of the operators.

The first complaint cannot be dealt with by electromechanical means, and this paper therefore takes no further notice of it. The second to the fifth complaints inclusive, however, contain features on which this paper has considerable bearing, and the author hopes to put forward suggestions for methods of working that will eliminate many of these troubles directly or indirectly. Complaint 6 is perhaps the most generally believed in and the most difficult to rectify. This assumes that the passing from the service of the Company to the Post Office has made the operating staff less conscientious and less faithful in the performance of their duty. If this be so, it can be rectified in time by discipline and careful supervision.

After carefully reviewing the systems in use and the operation of the same, the author has come to the conclusion that the plant is not as efficient as it might be, and some suggestions are here made for improving the efficiency of the plant and enhancing its value.

It must be recognized that the full automatic or machine telephone system must gradually replace the girl-operated system, but for economic reasons this cannot be introduced as quickly as telephone administrations would like, or as quickly as the public might demand, neither could the firms capable of manufacturing this equipment cope with the supply for the whole country within a period of from six to ten years. That system would therefore be outside the scope of the present paper.

An endeavour is here made to suggest improvements that can be introduced in a comparatively short space of time, and at a small increase of cost, on switchboards that are of modern pattern.

Responsibility for Service.

There are two parties responsible for the efficiency or inefficiency of the telephone service, viz. the operators at the central exchange and the subscriber's operating staff. The operator answers a call, tests the line wanted, and if the latter is idle completes the connection. In a manually operated system these duties are fundamental. In addition, at present the operator on receiving certain signals withdraws the plugs. If, however, the position is very busy, the operator may answer one or more fresh calls before withdrawal, with the result that between the time when the calling subscriber replaced his receiver and the operator withdrew the plugs that line would test "engaged" to any other caller. Again, either line desiring a second call during that period would cause a supervisory lamp to glow, and in the case of the called subscriber this lamp is on a position where he cannot be answered.

These weaknesses the author proposes to rectify by giving the equivalent of automatic disconnection, the instant removal of the engaged test when the subscribers replace their receivers, and the instant reconnection of the calling lamp to each line, so that the operator gets a definite calling signal if the receiver is replaced and then immediately removed.

The subscriber's staff can also greatly interfere with the efficiency of the service by operating it incorrectly. If every line ended on one telephone the service would be ideal as far as the subscriber was concerned, but he frequently has a switch for one extension line, or several lines on a switchboard, and with these he is given facilities for upsetting the service if he does not conform carefully to the instructions provided. The connection will probably be put through promptly, but when the ring-off signal is received from the extension line it is not acted on instantly, with the result that if the "central" operator has another call for the same subscriber, instead of getting the "main" station she gets the extension, or should the extension desire to call the main station the exchange will be called and the operator will find that she is not wanted. Obviously all these proceedings react to spoil good service. Usually the operating is left to the office boy, with the foregoing results. The devices described below will after a call cause the restoration of all apparatus to its normal condition to be automatic.

Automatic Disconnection on Manual Switchboards.

An invention which can speed up existing systems and make the essential and responsible operation on which the efficiency of the service most depends *automatic* and beyond the control of the operator is worthy of the gravest consideration. In addition to automatic disconnection each line tests idle immediately the receiver is replaced, the line lamp is instantly reconnected with its line, and the called subscriber is guarded against the caller not replacing his receiver promptly.

When the connection is through two or more exchanges

the advantages just mentioned are secured, and also the junction line is instantly released and made available for another connection. The carrying capacity of the junction lines will thus be increased, and in all probability the A operators' load can also be increased.

The conversion of an existing common-battery switchboard to automatic disconnection is a comparatively simple matter, it being necessary only to alter the connecting cord circuits by fitting in place of the lamp a special relay in the local circuit of the answering cord supervisory relay, and similarly another special relay in the local circuit of the calling cord supervisory relay, also adding two extra springs to the speaking key. On the junction circuit one cut-off relay of a simple pattern is required. Various modifications will be suggested to meet different conditions.

Lamp signals.—Preferably the lamp signals should be read in a method somewhat differently from that at present adopted. Usually a lamp associated with each line glows as a clearing signal. With the author's system it is not essential to withdraw the plugs instantly, as they have been rendered electrically inoperative when the receiver is replaced, and he therefore prefers that certain lamps associated with the cords should glow during the period of connection. A supervisor will then appreciate the condition of the operator's load much more readily, as a glowing lamp will indicate a live connection. Plugs, whether in their sockets or in multiple jacks, having non-glowing lamps in front, are available for instant further use. The glowing lamp will take less current than the shunted lamp at present used. For the same reason the junction lamp should also preferably glow during connection, the line being instantly available when the receivers are replaced, whether a plug is in a socket or a jack.

The benefits of the system are felt immediately after the first cord circuit is altered, either on a junction or a subscriber's position, so that the change-over may be gradual and can be carried out without the service suffering in the slightest. The alteration of the A position is of the greater importance.

"A" position circuit.—When automatic disconnection is to be introduced on the system using repeater coils, it will probably be found advantageous to introduce the cut-off relays in the local circuits of the supervisory relays. If the cut-off relays are made to take the place of the supervisory relays they must be similarly shunted, and might therefore be affected adversely by the variation of the line resistance. The local circuit method will be found the simplest and most economical method of converting an existing plant.

Fig. 1 shows an "A" position cord circuit so equipped. Cut-off relay D is connected in the local circuit of the shunted relay S′, the winding of which is connected directly in the line conductor. This relay is connected exactly as in ordinary practice, but now controls the cut-off relay instead of a supervisory lamp. All conductors from the plug A P are open on the relay D. The sleeve conductor has a parallel connection to the meter key, which is also normally open. Relay D is double wound, one winding being in the local circuit of relay S′ and the other in a local circuit controlled by two extra springs to be fitted on the speaking key. The calling cord relay D D opens all the conductors to the plug C P normally, and is controlled in the local circuit of relay S. When the present method of registering calls is retained, relay S is unaltered and is connected in every way as described for S_1. In the diagram, S is shown with a contact which momentarily earths a circuit for automatic registration and then opens the circuit again. Relay D D is double wound, one coil being in the local circuit of relay S and the other being completed by extra springs on relay D, so that relay D D is energized and controlled by D, and only when relay D permits is relay D D under the control of the station called for disconnection purposes. To prevent relay D, by the action of the calling subscriber, irregularly or unduly holding relay D D against the called party, the winding of D D controlled by relay S is a shunt across the

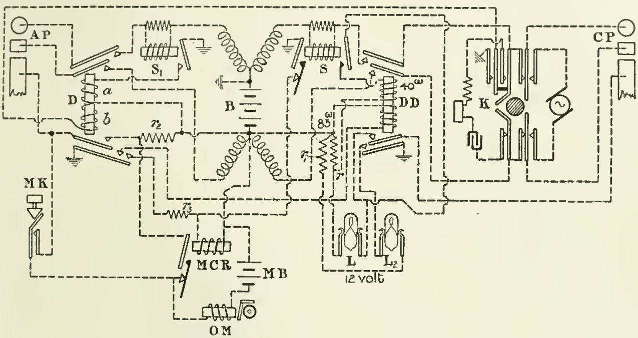


FIG. 1.

supervisory lamp L. When therefore relay S is de-energized by the called subscriber moving the switch-hook, it opens the shunt circuit so that the lamp L glows and calls the operator's attention to the irregularity. As long as it is energized relay D D also completes a circuit of the lamp L_2. It will be noted that the transmission circuit, the line circuits, and the multiple are absolutely unaltered.

Operating.—When the operator answers a call by inserting the plug A P in the jack of the line calling, and presses-over her speaking key K to join up her telephone, relay D is energized, as a local circuit is completed from earth at the key K through extra springs, through winding *b* of relay D to the battery. All conductors are then joined through to the calling line and relay S is energized. This completes another circuit through the *a* winding of relay D so that it remains energized after the key K is moved to another position and opens the *b* circuit. Current through r_2 engages the calling line. Relay D being energized also completes a circuit from earth at the lower contact of D through the lower winding of D D to the battery, so that D D is also energized and the lamp L_2 glows.

The operator tests the line wanted in the well-known manner and if idle inserts the plug C P. Ringing is done in the customary way. The supervisory lamp L then glows and continues to glow until the called subscriber answers.

When the subscriber answers, relay S is energized and completes the shunt circuit of the lamp L so that it ceases to glow. This coil is also the retaining circuit of relay D D.

The connection is now established. Should the calling subscriber replace the receiver, relay S_1 will be de-energized and open the circuit of relay D. D will become de-energized and open all the conductors to the plug C P and the circuit of the energizing winding of relay D D. The calling line will immediately test idle and the line relay and calling lamp will be re-associated with it, so that another call can be sent in on the line lamp.

Relay D D will remain energized until the called subscriber hangs up his receiver, when relay S will be de-energized and open the circuit of relay D D so that all conductors to the plug C P are opened, and the called line will now test idle and the line lamp be re-associated with the line. The lamp L_2 will cease to glow and the operator will know that the plugs are available for another call. Should the called subscriber be the first to replace the receiver, relay S will become de-energized and open the upper or shunt winding of relay D D so that the lamp L glows, but relay D D will remain energized by the circuit through the contact on relay D. If this lamp glows for an appreciable time the operator would challenge the calling circuit.

It will be readily appreciated that the plugs being rendered electrically inoperative it is not essential to withdraw them instantly, and they may be withdrawn at the convenience of the operator, or they may even remain in the jacks until required again for another connection.

For the same reason the negative clearing signal will be no disadvantage, as the connection is automatically disconnected by the subscriber, and it is believed that the lamps glowing during connection will be a valuable feature in continuously advising the supervisors of the condition of the operator's load.

Registering Telephone Calls.

Manually operated.—The calls may be registered in the well-known manner by pressing a meter key, and in the modified arrangement this key may be pressed either during the connection or at the termination of the connection before the plugs are withdrawn. The answering plug third conductor is connected in parallel with a spring of relay D and a spring of the meter key, both being insulated normally. If registering is done during the conversation the operator's meter and extra battery are in parallel with the resistance *r* (about 200 ohms), but if after, there is no resistance, as the circuit is open at the springs of relay D.

Automatic registration: meters in exchange.—The automatic disconnection system lends itself readily to automatic registration in a simple manner, particularly if the meters are retained in the exchange as at present. The existing circuit with the meter in parallel with the cut-off relay remains unaltered. One additional relay, M C R (Fig. 1), is required, and may be called the meter control relay. This has springs so arranged that it gives a momentary contact when energized. An extra spring is added to the cut-off relay D to complete a circuit for relay M C R. The resistance r_3 in series prevents relay M C R pulling up when relay D is first energized. When the resistance r_3 is momentarily short-circuited, relay M C R is energized, and is then retained energized by the circuit through relay D. The supervisory relay S has springs so arranged that when energized a momentary earth is put on relay M C R as before mentioned. As relay M C R is then locked in a local circuit further operation of relay S will not affect the circuit again.

Operation.—When the calling subscriber is answered and relay D becomes energized, a circuit is completed from earth through the contact of relay D, resistance r_3, winding M C R, to the battery. Resistance r_3, however, does not pass sufficient current to energize relay M C R.

When the called subscriber answers by lifting the receiver, relay S is energized and momentarily shunts the resistance r_3, and relay M C R is energized and remains energized because the current through it is sufficient for that purpose. Relay M C R on becoming energized momentarily completes a circuit from the main battery B, through the meter battery M B, the operator's meter O M, the contact of relay M C R, the contact of relay D, to the third conductor of the plug A P and the jack of the calling line, through the meter to earth, so that both meters register one call. Relay M C R is not de-energized until relay D has opened its contacts, so that it is impossible for relay M C R to send another impulse on becoming de-energized when the springs again momentarily make an earth connection.

If thought desirable a key M K may be fitted so that the operator can send an additional impulse when the call is of greater value than one impulse.

Meters at sub-stations.—When the meters are to be fitted at the subscribers' offices two meter control relays are necessary for each cord circuit (Fig. 2). Relays D and S are altered as before described. Relay R (Fig. 2) has two normally insulated contacts, connected one to each line at the plug side of relay D. Relay R is in a local circuit completed through a contact on relay D, so that relay R is energized immediately after relay D. Momen-

tary contacts are then made with the lines, but, as relay R R is not energized, the battery is not connected. Relay R completes a circuit for relay R R through resistance r_3, which does not allow sufficient current to pass to energize it. Relay R R is made to de-energize slowly. The momentary contact on relay S energizes relay R R by short-circuiting the resistance r_3. Relay R R is then held energized whilst the local circuit is completed through a contact on relay R.

At the sub-station the meter, which is made to de-energize slowly, is fitted normally in parallel with the speaking set. It may remain in parallel or be cut out of this circuit. When the relay part of the meter is energized in this circuit, a second or registering circuit is completed in parallel with the condenser, which is normally in series with the bell.

The operation is as follows :—When a subscriber makes a call, a circuit is completed through the relay winding of meter registers and then falls away, so that the condenser is in series to prevent current flowing normally. The meter is de-energized slowly so as to allow of the impulse being received. The relay R R is made to operate slowly so that it will not become de-energized until the impulse has been sent by relay R.

Meters at sub-station and exchange.—The existing meter arrangement may be retained at the exchange, and a connection made to the back contact of relay R, which is normally open at relay R R, so that an impulse may also be sent through the exchange meter when the calling subscriber replaces his receiver.

Junction Working.

Order-wire junction.—Fig. 3 is a diagram of a junction circuit in its simplest form showing only the features in connection with automatic disconnection. The special feature is the introduction of the cut-off relay R_2 on

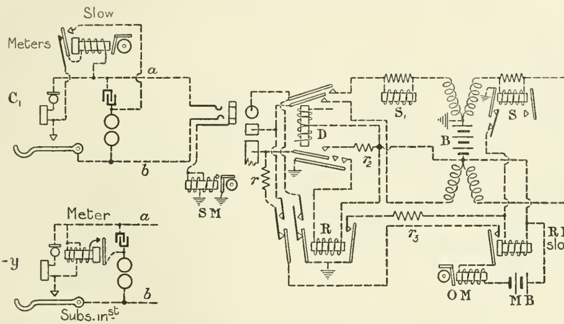


Fig. 2.

the meter in parallel with the speaking set, so that it operates to connect the registering circuit across the condenser and in series with the bell. The operator answers and connects relay D in circuit, and relay R is energized and causes momentary contacts to be made with the lines, but completes no circuits. Connection is made with the subscriber called, and, when he answers, relay S is energized and momentarily shunts resistance r_3, so that relay R R is energized and is retained energized by the circuit through relay R contact. Relay R R completes no circuit when energized, as the circuit is open at relay R.

At the termination of the conversation, when the calling subscriber replaces his receiver, relay D is de-energized and opens the circuit of R. As relay R becomes de-energized its springs make momentary contacts, which complete a circuit from the batteries B and M B, through the operator's meter O M, the contact of relay R R, the outer contact of relay R, to the ring of plug A P, over line *b*, through the bell and meter to wire *a*, the tip of plug A P, to the other contact of relay R, to earth. The sub-station which the three conductors of the plug P are normally insulated.

The four-wound repeater has the two windings on the line side connected through a condenser, which is shunted by the 12,000-ohm winding of a relay R. The repeater windings to the plug have the inner ends connected to the battery. One conductor to the plug has a supervisory relay R_1 in series (with a non-inductive shunt). This relay R_1, when energized, connects a low-resistance winding across the 12,000-ohm winding of relay R. Relay R completes the circuit of the cut-off relay R_2, so that it connects all the conductors through (with the exception of a break in the tip conductor). The back contact of the third conductor relay R_3 connects the operator's testing winding I C through a contact on the cut-off relay to the tip of the plug P, so that when the operator tests the line she may get a click in her receiver if it is engaged. The A operator must take up the line instantly it is allotted to her, so as to energize the disconnect relay and join up the B operator's testing circuit. To enable the B operator to

know that this has been done and that the test will be effective, a tone test device is connected in the circuit of the testing winding of her speaking set, by which she will get a low hum when she tests, if the cut-off relay is energized, on which the ordinary test will be superimposed. It is suggested that in a primary circuit of a coil and battery a suitable and distinctive tone would be received from a microphone, against the diaphragm of which a jet of air impinged. The cut-off relay also completes the circuit of a lamp, which glows until the cut-off relay is de-energized at the termination of a conversation.

Operating.—When an A operator receives a call for a line in another exchange, she asks for that number over a suitable order wire, and the B operator allots a junction to be used. The A operator has lifted the plug, such as C P in Fig. 1, and is waiting with her plug over the block of jacks appertaining to the exchange in question, so that she plugs in instantly. The 12,000-ohm relay R is then energized, and it in turn energizes the cut-off relay R_2. Relay R_2 joins the conductors through to plug P with the exception the calling line receiver has not been replaced. If the calling line receiver has been replaced, the cut-off relay D D will also be de-energized, and will open all the conductors to the plug C P, so that relay R is de-energized. This relay opens the circuit of the B-position cut-off relay R_2, and in de-energizing it opens all the conductors to the plug P, thus rendering it electrically inoperative. The called line now tests idle, and its line lamp is re-associated with the line in readiness for another call. When relay R_3 becomes de-energized it connects up the operator's testing circuit at that relay, but it is opened at a contact of the cut-off relay. The lamp L (Fig. 2) ceases to glow and the plug P may be withdrawn.

Any junction may be allotted for another call whether the plug is in its socket or in a jack—if the lamp is not glowing. The junction is thus rendered available for immediate further use when the subscriber replaces his receiver. Although a plug remains in the outgoing jack at the one end, and the junction plug may be in a multiple jack at the other end, they have both been rendered elec-

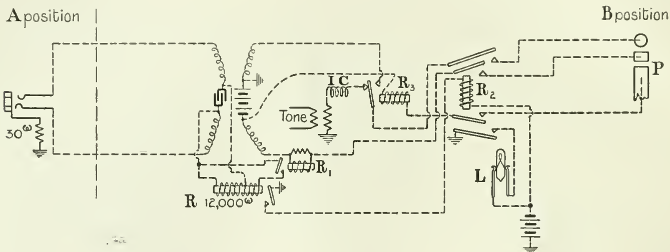


FIG. 3.

of the tip conductor, which remains open for testing purposes.

The B operator then tests the line wanted in the well-known manner, and knows by the faint hum received from the tone test device in series with the tertiary winding of her telephone set whether the line is engaged or not, that the test has been effective. The plug is inserted in the jack if the line is idle, and ringing is done in any of the well-known ways.

When the subscriber answers, the B operator's supervisory relay R_1 is energized, and this by putting a low winding in parallel with the high-resistance winding of relay R, actuates the A-position supervisory relay S so that the lamp L ceases to glow. When the junction plug was inserted, the sleeve relay R_3 was energized and cut off the operator's testing coil I C. The B-position lamp L glows during connection and until automatic disconnection takes place.

When the subscriber replaces the receiver after conversation, the supervisory relay R_1 at the B position is de-energized, and the low-resistance shunt on relay R is removed, so that the A-position supervisory relay S is de-energized, and allows the supervisory lamp L to glow if trically inoperative by having all their conductors opened. The operators will withdraw the plugs as quickly as possible, but they may delay this until it can be done without interfering with the efficiency of the service.

Automatic calling on junctions.—When no order wire is used the insertion of a plug at the outgoing end automatically lights a lamp at the B position as a calling signal. Such a circuit is shown in Fig. 4.

The repeater, with its windings connected to the condenser and the battery, is exactly the same as on order-wire junctions, as is also the 12,000-ohm relay R and the supervisory relay R_1 at the B position. The relay R_1 does not directly control the cut-off relay R_2. All conductors to the plug P are normally insulated at relay R_2. The cut-off relay R_2 is double wound, one winding being completed in a circuit with the battery through an extra contact on the speaking key, which is closed when the operator presses over the lever to answer a call. The second winding has one side connected to the battery and the other to an inner contact of the cut-off relay, the associated moving spring being connected to the contact of relay R, the outer contact of the same moving spring being connected to the calling lamp and battery. When

the operator puts over the key to answer, relay R_2 is energized and cuts off the calling lamp C L. A retaining circuit is then completed from earth at relay R, through the moving spring and the inner contact and winding of R_2 to the battery, so that when the operator cuts off her telephone the cut-off relay R_2 will now be controlled by relay R. A supervisory lamp S L is connected in parallel with the retaining coil of the cut-off relay, so that it glows as long as this relay is energized. The speaking and ringing key K is connected between the contacts of the cut-off relay and the repeater.

Operating.—When the A operator has a call for a line in another exchange she tests in the well-known manner for an idle line, unless a visual test or other device is provided to indicate what lines are engaged. When the plug, such as C P (Fig. 1) is inserted, the 12,000-ohm relay R is energized, and a local circuit for the calling lamp C L is completed. The B operator pushes over the speaking-key lever to join up her telephone, and a local circuit is also completed through one winding of the cut-off relay R_2, so that it is energized to cut off the calling lamp C L and complete the retaining circuit previously mentioned. It also completes the circuit of all conductors through to the plug P. The supervisory lamp S L also glows. The operator tests and rings in the usual manner.

When the called subscriber answers the supervisory relay R_1 is energized and shunts the 12,000-ohm winding, so that the supervisory relay S (Fig. 1) at the A position shunts and puts out the associated lamp L, and the holding circuit of the cut-off relay D D at that position is completed.

When the called subscriber hangs up his receiver after a conversation, the B-position supervisory relay R_1 is energized, and the shunt removed from relay R, so that if the calling subscriber has replaced his receiver the A-position supervisory relay S and the cut-off relay D D are de-energized. All the conductors to the A-position plug C P are therefore opened, and the B-position relay R is de-energized. This opens the retaining circuit of the cut-off relay R_2, so that it is de-energized and opens all the conductors to the plug P, allowing the line relay and lamp to be re-associated with the called line and the line to test idle. The supervisory lamp S L ceases to glow and the calling lamp C L is re-associated with the junction line.

The junction line has thus been automatically disconnected at both ends instantly and is available for another call even although the plugs have not been withdrawn. The onus of determining disconnection is on the calling subscriber, and should he fail to hang up his receiver the called subscriber calls the operator's attention to the irregularity when he hangs up his receiver by causing the supervisory lamp to glow. The caller, immediately he hangs up his receiver, re-associates his calling relay and lamp with his line and causes it to test idle, but does not release the called line. The called subscriber must replace his receiver to release his line and also the junction line.

It is believed that the fact of the supervisory lamps glowing during conversation will be a very valuable feature from the point of view of supervision, particularly in enabling a traffic supervisor to note at any period of the day the load of the position and the load of the junction lines. It is reasonable to expect also that the carrying capacity of the junctions will be increased, as they cannot be delayed by slow releasing of the lines.

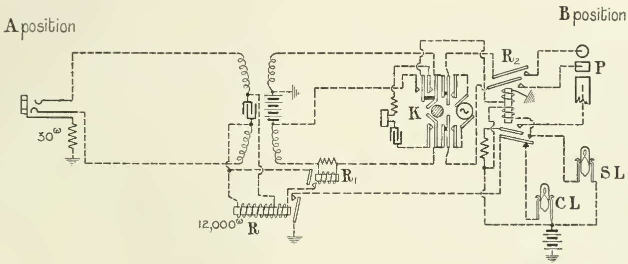


Fig. 4.

Junction working with the B Positions Unaltered.

In certain circumstances it may not be considered advisable to alter the incoming ends of the junction lines on the B positions. This at any rate might be delayed without sacrificing a very great deal of the efficiency of the system. When two lines are joined together locally, *i.e.* in the same exchange, the full advantage would be obtained if the board were of the complete multiple type. If, however, it were worked on the transfer system, and in the case of connections through another exchange, all the advantages would be obtained with the exception of the automatic disconnection at the B position and the consequent instant release of the called subscriber's line. His line would test "busy" and the line lamp would not be re-associated with the line until the operator withdrew the plug as at present.

Owing to the high efficiency of the operating at these positions this might not amount to a great deal, and might not be noticed in service tests.

The junction would be automatically released when both subscribers replaced their receivers, and the clearing signal would be instantly given to the B operator. That

operator by the lamps glowing would know what lines were idle although she had not had time to remove the plugs and could again bring the lines into use by removing the plug from one part of the multiple to another.

The private branch exchange lines at each end of the circuit would both be instantly automatically disconnected, all the lines would be opened at the A position, and the clearing signal would be given at the B position.

When the connection was through two exchanges the loss would be somewhat greater, as the clearing in the second exchange would depend on the withdrawal of the plug at the first exchange.

System using Disconnecting Keys.

For small multiple switchboards for public service, or as branch exchanges in subscribers' offices, the author prefers

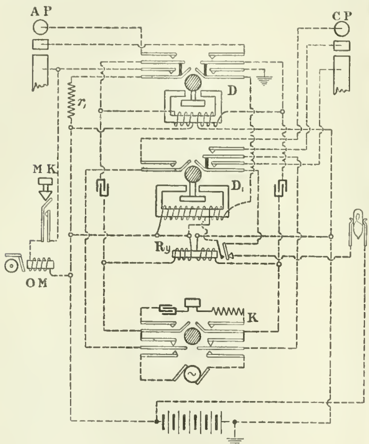


Fig. 5.

to use keys to take the place of the relays formerly described. Fig. 6 shows a combined speaking, ringing, and two disconnecting keys mounted on a common frame, the two latter keys being electromagnetically controlled. This arrangement is very compact. The "Stone" system of transmission is best adapted for use with electromagnetic keys as it is not then necessary to shunt them; preferably used with a 40-volt main battery. The circuit is shown in Fig. 5. When the operator presses over the speaking-key lever to join up her telephone, it engages with the two levers of the cut-off keys and forces them over also.

The coils of the keys are joined to the conductors by the springs, the inner ends of the coil D being connected to the battery. As the caller's microphone is then in circuit current flows through the coil of the answering-cord key so that it is retained after the speaking key is moved to another position. The springs of this key also complete a circuit of one winding of the key in the calling circuit, so that it also is retained and connects the conductors through to the calling plug. A double-wound relay is connected across the loop with the inner ends connected to the battery, and current is supplied through this to the called subscriber's microphone. The supervisory lamp circuit is completed by the back contact, and the holding circuit of the cut-off key by the front contact. The former enables the called subscriber to signal the operator should the caller fail to replace the receiver promptly after conversation.

When the caller replaces his receiver the cut-off key D is de-energized and opens the conductors, so that his line

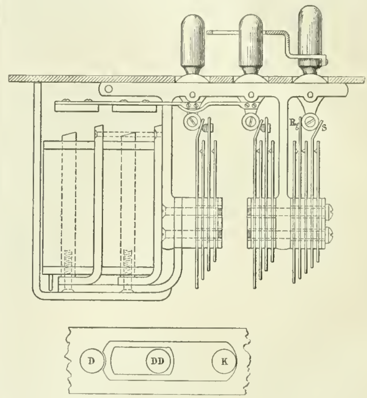


Fig. 6.

tests idle, and a second call can be sent in instantly. The energizing coil of the calling cord key is also opened, but it is still held operated by current over the line, maintaining relay R_y energized, and only when the called subscriber restores his receiver does relay R_y and key D′ become de-energized and open all conductors to the plug C P so that his line tests "idle" and his line lamp becomes re-associated with his line.

As the circuit is opened when the caller's receiver is replaced, and cannot be re-established without the intervention of the operator, the answering cord should then be reckoned as "idle," but the operator must wait until the second lever returns to normal before withdrawing the calling plug to avoid re-associating the called subscriber's calling lamp with the line until the receiver is replaced.

Private Branch Exchanges.

Automatic disconnection is particularly applicable to this type of installation of the non-multiple kind in subscribers'

offices. It is essential, however, in order to obtain all the advantages described, to use line and cut-off relays instead of a line relay with a break jack as is usual.

With a view to reducing the cost and saving space, combined or twin relays should be used. These are common in automatic practice, but have not hitherto been used in manual systems. A common core is used with a central ring, which with the armatures and magnetic returns complete two independent magnetic circuits. Fig. 7 shows a suitable design.

The cord circuit is illustrated in Fig. 8. The keys are shown separated in order to simplify the diagram. The electromagnetic key D takes the place of the answering cord supervisory signal and the bridging coil through which current is fed. There are no condensers in the conductors, and the double winding of the cut-off key is connected across the loop when the key is operated, with the inner ends connected to the relay R_y contacts. When relay R_y is not energized another coil B is in series with the windings to complete the circuit, but when the relay is energized the windings are connected to a local battery or feeder mains to supply current for a local connection. The supervisory signal is replaced by a relay R which shunts the lamp L and also controls the slow-acting relay R_3 so that the local line connected to the answering or calling cord can disconnect the circuits. Relay R_2 is a retaining relay which is energized when the bridge is completed across the loop by the lever being pressed over and the momentary contact x completed. Relay R_2 thus keeps the circuit completed when the operator moves the key K to the ringing position, until the called subscriber answers. Relay R_3 then short-circuits R_2 so that it is de-energized, and thereby relay R controls the connection and opens the circuit at the termination of the conversation. Relay R_3 is slow to release to allow R to pulsate the lamp L when the switch-hook is moved to call the operator. This allows calls to be transferred from one station to another.

The line circuits on the jacks are somewhat modified. Each exchange line has two jacks, the upper or answering jack having the bush insulated, while the lower or calling jack has the bush connected through an 80-ohm resistance to earth. The line indicator with a condenser in series is permanently connected across the exchange line. The cut-off relay coils on the local lines are of high resistance —say 500 ohms. In the cord circuit the calling plug has the third conductor connected through a low-resistance relay R′ to the battery and earth. When energized, this relay by one set of contacts opens the circuit of relay R_y and connects the sleeve of the plug A P through the resistance r to the battery and earth, so that the cut-off relay of the extension line may be energized. Relay R_1 by another set of contacts switches the battery through one winding of the coil of the cut-off key D from one side of the supervisory relay R to the other, so that relay R is always associated with the local line.

When a call is received from the exchange the plug A P is inserted in the upper jack A J, and, as the bush of that jack is insulated, relay R_y is not energized when the levers of keys K and D are pressed over. A circuit is then completed from the main exchange battery through the cut-off key winding D D in the calling cord there, over the line

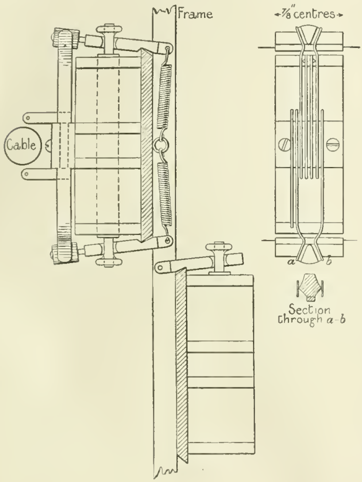


FIG. 7.

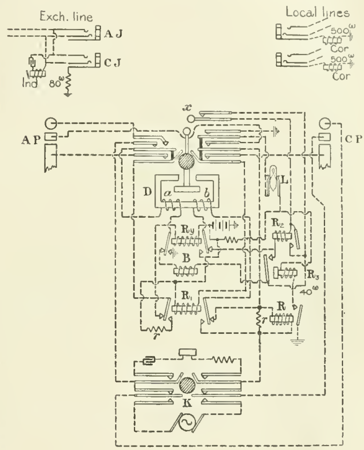


FIG. 8.

circuit, through the windings of key D at the private branch exchange, through coil B, and the winding of relay R_2, the circuit having been momentarily closed by the contact *x* of key D which caused relay R_2 to be energized and be retained. The holding circuit of D D is thus completed at the main exchange, and the supervisory lamp shunted out, and at the private branch exchange the cut-off key D and relay R_2 are energized, and they remain in that condition after the key K is moved to the ringing position. When the plug C P is inserted in the jack of the line wanted the cut-off relay is energized, but the relay R_1 is biased against this current.

When the called subscriber answers, a circuit is completed through relay R, which shunts out the lamp L by the 40-ohm winding of relay R_1 that is also energized, and it short-circuits the winding of R_2 so that it is de-energized, and relay R_3 completes the circuit for the bridge across the loop.

When the called subscriber replaces the receiver, relay R, through relay R_3, opens the bridge circuit so that key D is restored to its normal position, indicating to the private branch exchange operator that the cords are available for further use. Key D in turn opens the line circuits and de-energizes the key D D at the central exchange. The exchange line has thus been instantly cleared at both ends and made available for another connection in either direction.

When a call originates with a private branch exchange line the plug A P is used for answering, and the key is thrown over, a circuit then being completed through relay R_y and the cut-off relay C O R. Relay R_y connects the battery between the two windings of the key D so that the caller can talk to the operator. If connection is wanted with the exchange the plug C P is inserted in the lower or calling jack C J. A circuit is then completed through the 80-ohm spool on the jack bush, through relay R_1, and the latter relay cuts the circuit of R_y so that it is de-energized and replaces the local battery by the coil B, as current for the microphone on an exchange connection is to be fed from the central battery. Relay R_1 also connects the winding of the coil D to the plug C P side of relay R, so that the latter is associated with the circuit of plug A P. The exchange is called automatically, as the coil B completes the loop circuit. The springs of relay R should be so adjusted that they make contact before breaking, so that the key D may not release. Relay R will energize, and will in turn be cut out of circuit when the relay R_3 is energized. The calling line cut-off relay will be kept in operation by current through the resistance *r*. At the central exchange the answering cord key D will be maintained energized over the caller's line and microphone. When the caller's receiver is replaced, relay R will be de-energized and by relay R_3 open the circuit of coils B and D, so that the key D′ at the central exchange and the key D at the private branch exchange will be simultaneously de-energized, and the line will be instantly cleared at both ends.

Should a local connection be contemplated the plug A P will be inserted in the caller's jack and relay R_y will be energized, so that current will be provided for the calling line; and when the plug C P is inserted in the called line jack, relay R_1 will not be energized, so that current will be available to energize both microphones. In such a case the circuit will be automatically disconnected only when the receivers at both stations are replaced.

It is thought that a single cut-off key will not be objectionable on these small boards, because there would always be a plug over a lamp which might glow if the called subscriber kept his receiver in his hand after the caller had replaced his receiver.

Suitable circuits are also provided for giving automatic disconnection on extension line switches and on cordless switchboards.

DISCUSSION ON

"THE EMPLOYMENT OF POWER IN H.M. POST OFFICE."*

SCOTTISH LOCAL SECTION, 13TH JANUARY, 1914.

Mr. W. W. LACKIE: The use of electrical energy in the Post Office can never be dissociated from the name of the late Sir William Preece, who preached and practised the doctrine that electricity is the poor man's light so successfully that electric light was adopted in the principal post offices throughout the country; he thereby was of considerable assistance to the electrical industry when such assistance was much needed. It is evident from Mr. Gunton's paper that electricity in the Post Office has passed through the same cycle of development that it has done elsewhere. That is to say, they began by adopting electricity for lighting, and then proceeded to use it for power, until now the power load is greater than the lighting load. It may be of interest to mention that 22 years ago the Post Office in George-square, Glasgow, was supplied with electricity by a private company who had a power station in a basement, two storeys below the street level in Miller-street. There were three arc-lighting machines, each machine being capable of lighting three arc lamps; and the two plants comprised two 75-h.p. engines with generators and these three arc-lighting machines, one of which is now housed in the entrance hall of Port Dundas electricity works under a glass case. When the Corporation took over the electricity supply in Glasgow the Post Office authorities installed plant of their own in George-square, but in the near future they are to take the whole of their supply from the Corporation.

The curves given by Mr. Gunton for hydraulic and electric lifts are most interesting and will be very useful. They remove all doubt as to whether an electric or a hydraulic hoist is best for an ordinary office, as the number of journeys in such cases is certainly 100,000 per annum. If any criticism could be made on this paper it would be in regard to the General Post Office's erecting a comparatively small private generating station in London. I would also suggest to the author that he should further investigate the cost of electric cooking.

Mr. A. PAGE: There is one point which specially interests me in connection with the paper, namely, the relays that protect the supply in the event of a failure of the power-station plant. I should like to know if before this system becomes properly operative the sub-stations are shut down and are started from the battery; because if they are not, and we assume them to be running upon practically the full load, the battery must be a very large one indeed before it can take up a load of 1,250 kw. Our experience at Glasgow is that discriminating relays are not to be depended on, and we are tending to do away with them instead of extending their use. Another point is how is the power station restarted in the event of the battery's carrying the sub-station load? Is the sychronizing done at the power station or sub-station end of the feeders, and how is it effected? Has the earthing of the star-point in the case of a pressure of 6,500 volts proved satisfactory? We do not think that it is necessary to earth here, as we generally manage to keep running when we have an earth on one side; that, of course, presupposes that the insulation on the other two phases is very good. I wish we could get in Glasgow an average rate of 1½d. for a supply of power and lighting with such a good load factor. The daily load factor is given as 70 per cent and the weekly load factor as 56 or 59 per cent. It would be interesting to hear what the yearly load factor is, as that is the factor which counts.

Reference is made to belt-driven air compressors as against a direct drive, and the author says that in smaller installations belt-driven sets are employed because they are more efficient and economical. A little more explanation on that point might be given. We are told that gas is sometimes drawn into the street tubes run on the suction or vacuum system. Unless special arrangements are made that must cause a great deal of trouble. I should like to know how this gas is in the first place detected and then got rid of. We are unfortunately occasionally called upon to find out the position of faults in electric cables, but a blocked pneumatic tube must be a worse problem and present considerable difficulties in ascertaining where the carriers are fixed and how they are to be got at. It must presumably mean opening up the ground. The curves in connection with lifts may prevent our recommending the electric drive in the future when it is wrong to do so and when we might well leave the field to the hydraulic engineer. I do not think there will be many cases of that kind, but it is well to know the pitfalls of which we have got to keep clear. A single unsatisfactory installation leads to a good deal of talking, and that must be avoided. In conclusion, Scottish members would have liked the author to refer to "British firms" instead of to "English firms."

Mr. G. STEVENSON: I should like to ask the author why he adopted different types of converting machinery in the various sub-stations. I notice that in the Blackfriars station there is a 35-kw. synchronous motor-generator, and in the G.P.O. west sub-stations motor-converter sets. I should be glad if the author would state in his reply the reason for adopting synchronous motor-generators. I suppose it is for the purpose of improving the power factor. In regard to the 440-volt three-phase power supply, I should like to know what proportion of the load consists of induction motors; as far as I could make out from the diagrams in the paper the greater part of the load consists of lighting. I take it that at any rate the compressor plant would be driven by induction motors; if that is so, the total load would be somewhere in the neighbourhood of 960 b.h.p.

Mr. A. P. ROBERTSON: I noticed particularly one point with regard to electric traction. I take it that the testing track for the battery trucks is level and that the trucks have only at the present time to be used on subways. It seems to me a curious way to test a loaded vehicle upon a level surface without taking account of hills and rough road surface. When ascending a hill the vehicle takes

* Paper by Mr. H. C. Gunton (see pp. 109 and 202).

Mr. Robertson.

much more current than might perhaps be expected on first consideration, and for general road traffic it is bound to take still more when it has to run on all sorts of roads. I should like to know if the truck system is intended for use on the streets or only indoors for Post Office traffic, or on subways from post offices adjacent to railway stations.

Mr. Gunton.

Mr. H. C. GUNTON (*in reply*): Mr. Lackie has naturally referred to the question of our supply of electrical energy, and I should like to make it perfectly clear that the $1\frac{1}{2}$d. per unit to which reference has been made is the cost per unit delivered for lighting and power in London. We have had to wait some time to justify the shutting down of our station in Glasgow, the reason being that we have used our exhaust steam for heating purposes; but we are now in a position to take a supply with economy and in a convenient and safe form from the Glasgow Corporation mains.

With regard to the points raised by Mr. Page, the transference of the load to the battery is quite automatic. The continuous-current busbar relay, on reversal taking place, causes the boosters to be automatically shut down and short-circuited; this is desirable, as their voltage might at the time be opposing the voltage of the battery. The pneumatic load and the power load at King Edward Building would also be removed automatically if the conditions of the load and the state of the battery at the time were such that it would not have been safe to leave these tripping circuits inoperative and so attempt to maintain the power load as well as the lighting. The next step would be for the shift engineer to open the booster tripping circuit, start up the boosters again, and add their voltage to that of the battery in order to keep up the pressure of supply and facilitate synchronizing again with the power station. He would then communicate with the power station, and if the trouble was not likely to be of long duration he could open the remaining tripping circuits and so enable the power motors to be started up again. This arrangement has been called upon to act in the manner described, and has never, so far, failed us as regards maintaining the lighting supply. We have never had any difficulty in synchronizing and switching in with the power station. The question as to whether an earthed or unearthed neutral is the best is one which has often been discussed and upon which opinion has always been divided.

Mr. Gunton.

The advantage of the belt-driven compressor is that a high-speed electric motor can be used with a low-speed compressor, which we have found to give very satisfactory running results. So far as dealing with gas leaks is concerned, we test for gas periodically, and when it is found we depart temporarily from the "pumping through" system and deliver from the vacuum pump into the atmosphere instead of compressing up to the operating pressure. We have in addition fitted anti-explosion doors and duplicate mains so as to be able to keep the latter quite free from oily deposits likely to give rise to spontaneous combustion. I am glad Mr. Page has drawn my attention to the expression "English firms." The reference should certainly have been to "British firms."

Replying to Mr. Stevenson with regard to the two different types of transforming machinery in the sub-stations, continuous current was necessary in any case for battery charging, and was preferable for driving the pneumatic pumps. It was decided to combine as far as possible, by means of a composite system, the advantages of both the alternating and continuous-current systems of supply. The continuous-current plant, which requires constant attention, is concentrated at one of the three sub-stations and is operated in such a manner as to maintain the power factor of the whole system at a high figure without seriously lowering the overall efficiency, while the battery provides a valuable factor of reliability in connection with the supply from all three sub-stations.

WESTERN LOCAL SECTION, 19TH JANUARY, 1914.

Mr. Tremain.

Mr. F. TREMAIN: As regards conveyers, I have calculated that the one installed at the Bristol head post office could handle if necessary 500 tons per day. In connection with the "general lighting" of large rooms, I do not think we have yet got a perfect system, as in the instrument room at Bristol some of the officers recently experienced difficulty due to the shadows cast by their own bodies. The lamps have, however, been re-arranged to overcome this difficulty. The ideal system for a telegraph instrument room is indirect lighting, and I hope that with the advent of the $\frac{1}{2}$-watt lamp such rooms will be illuminated in this way. The desirability of white walls and ceilings is beginning to be realized and will no doubt contribute to a perfectly satisfactory illumination of rooms of this kind. Where plant has been installed on a power basis for lighting a large office, it would be interesting to know the ampere-hour capacity of the battery, its relation to the number of kilowatts installed for lighting, and the length of time that such a battery would efficiently run the whole of the lamps without recharging. A battery which would provide the supply for the whole of the week-end in a big post office would be exceedingly large, and I should like to know if such a battery has really been installed at the General Post Office, London.

Mr. Tremain.

It may be of interest to mention the lighting and power requirements of the Bristol Post Office and to consider the effect on the load factor of the supply station. The lighting installation is equivalent to 60 kw., and power to 55 kw. It is a lighting load which unfortunately comes on at the peak of the load, being coincident with that due to the residential and other demands. It would be to the mutual advantage of the Post Office and supply authorities if batteries were more generally installed in post offices for this purpose and the whole of the energy taken from the public supply between, say, 11 o'clock at night and 8 o'clock in the morning, as well as during certain hours in the daytime, energy for lighting being taken from the battery at other times. I raised the same question about eight years ago at Newcastle, but the subject was not then ripe for discussion. It would be interesting to know what should be the ampere-hour capacity of the battery in relation to the total kilowatt capacity of an installation for this purpose. At Bristol last year 74,000 units were used for lighting (that is 1,200 per kilowatt installed) and 40,000

units for power (about 700 per kilowatt installed); the average cost was nearly 3d. per unit. If comparatively small stations can generate energy at 1¼d. per unit as has been stated, including capital charges and depreciation, the Post Office has a strong case for better terms from the public supply authorities. We know that small country-house stations can generate energy at less than 1d. per unit. I suggest that the Post Office should take current from the public supply authorities in large towns at the most convenient period when the generating plant is nearly idle, and arrange terms to their mutual advantage, thus avoiding the necessity of increasing the size of the mains, etc., to provide for the ever-growing peak load due to lighting and cooking. In the South-Western engineering district there are some 20 towns where a supply of electrical energy is taken for lighting and power in post offices from the public supply authority. I should like to see every post office lighted by electricity, and where the supply cannot be obtained from this source, I would suggest the installation of small "country-house" generating sets.

Mr. W. A. Chamen: There are quite a number of small towns in which the electricity supply companies are in a position to supply electrical energy to the local post offices in the same way that the municipalities do in the case of large towns. I am surprised that the Post Office is constructing an underground railway of its own, in view of the large number of underground railways that already exist in London.

Mr. J. W. Shergold: I was specially interested in seeing the electrically-driven Silvertown truck. It collected parcel baskets from the various floors of the Post Office building, passed up and down all gradients, reached the street with ease, and finally arrived at the platform at Temple Meads station needing only one man to control it. The running of motor vans from large centres to and through outlying districts has resulted in a considerable saving to the department.

Mr. A. T. Kinsey: I should like to know what is the charge per unit for power at Birmingham and other places where post office generating stations have been shut down. I was pleased to see the diagram of the new sluice in connection with pneumatic tubes. It has hitherto been difficult to find a sluice which would hold the air, and if the new apparatus referred to proves satisfactory a considerable advance will have been made.

Mr. E. A. Pink: My experience of the Silvertown truck has been very satisfactory, and the truck has had severe tests. I should like to mention specially the great ease with which it can be controlled and the speed adjusted from 2 to 6 miles per hour as desired.

Mr. H. C. Gunton (*in reply*): From Mr. Tremain's remarks there appears to be some misunderstanding with regard to the length of the King Edward Building conveyer, which is about 400 feet long. Up to this distance a continuous conveyer is the most suitable contrivance if room can be found for it. As regards general lighting of instrument rooms, no doubt in various offices it has been necessary to adjust or depart in detail from the systems referred to, in order to obtain satisfactory results and meet local requirements. Indirect lighting would be very effective, but it is doubtful whether the Post Office authorities would feel justified in going to the expense of providing it in sorting and instrument rooms. The Post Office has installed batteries in order to get the most favourable terms from the local suppliers of electricity (not necessary municipal) by raising the load factor, a stand-by being obtained at the same time. With regard to the capacity of the battery required to deal with the load in an emergency, the Birmingham battery has a capacity of 750 ampere-hours, and that in London 2,000 ampere-hours. This is sufficient to keep the power and lighting going for half an hour, and lighting alone for several hours. The manner in which the battery maintains the supply has been described in my reply to the discussion on this paper at Glasgow.* It is very satisfactory to have been able to obtain a British-made battery truck. The Edison battery has certainly taken a long time to develop, and it has been employed in this case principally because there was good ground for thinking that it could be used more roughly. The Silvertown truck has proved very satisfactory so far, but it is necessary that it should receive a more lengthy trial.

As regards the Post Office Railway there is plenty of room at the depth at which the Post Office work—the tunnelling is principally in clay, so that it is not necessary to use compressed air, and it is quite possible to work close to other people's property without doing any damage.

Where there is a complaint as to the lighting, a lumeter should be obtained and the amount of light measured at the point where it is being used.

In reply to Mr. Kinsey, it is as a rule necessary to obtain a price below 1d. per unit from public supply authorities before the Post Office is justified in shutting down its own plant, as the exhaust steam is used as a by-product. As the Post Office has to install separate heating plant when an outside supply is taken, it is necessary to consider the total cost of the installation, including heating, under the new and old conditions before making any change. With regard to ventilation, it is usual to use the extractor type of fan in conjunction with radiators.

* See page 330.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF THE 22ND JANUARY, 1914.

Proceedings of the 561st Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 22nd January, 1914—Mr. W. Duddell, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 8th January, 1914, were taken as read, and confirmed.

Messrs. B. B. Heaviside and R. Grigg were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

Elections.

Members.

Fortescue, Cecil Lewis.
Kennedy, John McFarlane.

Associate Members.

Evans, Llewelyn, Capt., R.E.
Fogarty, Laurence Francis.
Gillitt, Leonard.
Stamatopoulos, Andrew George.
Tanner, George Frederick.

Graduates.

Pahwa, Sundar Dass, B.Sc.
Walker, Ernest.
Wilson-Jones, Richard.

Students.

Bailey, Alan John.
Boscolo, Gioachino Ricardo.
Bromley, James Treasure.
Burleigh, Robert.
Eastman, Hugh.
Ethelston, Simon.
Giller, William Leslie.
Halford, William Charles John.
Hedgcock, Archibald David.
James, Malcolm Reginald.
Johnston, Ernest Clifford.
Killingback, Stanley Gordon.
Maidment, Roland Frederick J.
Mould, James.
Nath, Pandit Ragho.
Norman, Archibald Cuthbert.
Organ, Harold Percy.
Pendlebury, Stanley.
Rashid, Mohamed Abbas.
Vick, Ernest Henry.
Wilcock, Eric John.
Wong, Sid Lam.

Transfers.

Associate Member to Member.

Coombs, Allen Murray.

Student to Associate Member.

Connan, John Cranmer.
Hills, Stanley Moncœur.
Howarth, Oliver.
Page, George Wood Pearce.
Phillips, Thomas Francis.
Rennie, John Cameron.
Snowball, Bartholomew.

Student to Graduate.

Grant, Edgar George.
Spary, Percy George.

Donations to the *Library* were announced as having been received from The American Institute of Electrical Engineers, P. Boucherot, H. H. Broughton, The Canadian Department of Mines, Messrs. Constable & Co., Ltd., V. A. Cornelius, J. Eck, A. P. M. Fleming, The Institution of Civil Engineers, R. D. Lillibridge, La Lumière Électrique, M. Maclean, D.Sc., A. J. Stubbs, The United States Department of Commerce, R. M. Walmsley, D.Sc., L. H. Walter, and W. T. Wardale ; and to the *Museum* from K. Hedges and The Norwegian Telegraphs Department, to whom the thanks of the meeting were duly accorded.

Sir Oliver Lodge, D.Sc., F.R.S., then delivered the Fifth Kelvin Lecture, entitled "The Electrification of the Atmosphere."

A vote of thanks to the lecturer was proposed by Dr. R. T. Glazebrook, C.B., F.R.S., and seconded by Professor Silvanus P. Thompson, D.Sc., F.R.S., and the resolution was carried with acclamation. The meeting adjourned at 9.45 p.m.

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THE FIFTH KELVIN LECTURE.

THE ELECTRIFICATION OF THE ATMOSPHERE, NATURAL AND ARTIFICIAL.

By Sir Oliver Lodge, D.Sc., F.R.S., Member.

(Delivered 22nd January, 1914.)

When the President asked me to give the Kelvin Lecture he told me that it had no necessary connection with Lord Kelvin: he practically said, I think, that I might if I liked keep clear of Lord Kelvin; but in dealing with any branch of physics I find that quite impossible. I have always found in lecturing to students on almost any of the larger groups of physical science that Lord Kelvin was at the bottom of them; and in this matter of atmospheric electricity he began, I think I am right in saying—Professor Silvanus Thompson knows much more about these historical matters than I do—but I think I am right in saying that he practically began the accurate measurement of atmospheric electricity, devising instruments for the purpose and carrying out a number of measurements.

For measuring an atmospheric potential one method used to be to put an earth-connected sphere up to the place required, then to insulate it, carry it indoors by an insulating handle, and determine its charge. The sphere in a place where the potential, we will say, was naturally high was kept at zero potential by being earth connected. That could only be by its possessing an opposite charge sufficient to neutralize the natural potential in its neighbourhood, and if that charge is measured we get a measure of the potential which is due to it on the sphere.

Lord Kelvin, however, preferred not to use an earth-connected body, but to employ an insulated body and to bring it to the potential of the place considered by making it grow and break bits of itself off. Thus taking, let us say, a sphere once more, and putting it in its place with an elongated conductor connecting it to an electrometer, it would have an opposite charge induced upon it, even though insulated; but if made capable of emitting a series of proof planes, that is of emitting parts of its surface containing this opposite charge, that opposite charge might be got rid of, and so it would be bound ultimately to acquire the potential of the place where it was. That is the method of the smoking match, and of the water dropper. In both cases they are conductors which grow and break bits of themselves off; they throw off the oppositely charged bits, and thereby gradually acquire the right potential. To measure the potential of a conductor is as easy as possible; simply connect it to an electrometer of either insignificant or of known capacity. To measure the potential of an insulator is not so easy, because how is it going to be connected? Well, that is the method, the water-dropper method or the smoking-match method, or some mechanical device which is practically the same thing. For portable work, work in the field, the smoking match is the best, the smoking rod. For recording work in an observatory the water-dropping method is the best. Lord Kelvin it was who devised these methods, and Observatories still use a jet of water which gradually grows and breaks into drops at the place whose potential is required.

As this is a Kelvin Lecture, I should like to throw on the screen some portraits of Lord Kelvin in different stages; first in the stage in which everyone in this room was familiar with him. Next I will show him in the stage when he had achieved his great work on the Atlantic cable, the stage soon after which I was privileged first to know him, a portrait which was given me by Lady Kelvin with the remark that she considered it the best that had been taken. Some in this room knew him then, but many did not at that age. Then there is the previous stage in which I expect nobody in this room knew him, Professor William Thomson of Glasgow, while he was engaged upon his, I was going to say, superhuman work in the highest parts of mathematical physics, in the forties and fifties of last century, before the fascinating problems of the Atlantic telegraph withdrew him to some extent from pure science into applied science, and made him three times President of this Institution.

It was at this earlier time that he began his atmospheric electrification experiments, and here is his portable electrometer with a tall rod terminating with a smoking match for measuring the potential of the atmosphere at the place

where the smoke particles are given off. That is the conductor which is growing and spitting away parts of itself in the form of smoke powder.

The portable electrometer employed in connection with this collector—I do not know that it is so much used nowadays—was one form of those attracted-disc electrometers which he devised and found most suitable for many purposes. For stationary positions his quadrant electrometer is of course more sensitive.

Here in Fig. 1 is a record of the meteorological observa-

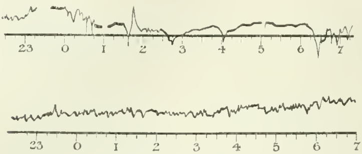


FIG. 1.—Results obtained by Self-recording Quadrant Electrometer with Water-dropping Collector.

tion of atmospheric electricity, I think at Kew, on two different days, made by a quadrant electrometer attached to a water-dropping collector. The lower diagram shows the positive potential of the higher air on a fine day, under fine weather conditions, a very steady positive potential. The upper diagram represents the conditions on a wet day. The potential has to struggle down to negative against the normal potential, for the upper air is normally positive. The earth is negatively charged; the levels above are positively charged. One is a cause of the other no doubt; there may be a question as to which is which. I myself think that the upper layers being positively charged is the chief cause of the negative electrification of the earth's surface, though there is always a possibility that any given planet is itself negatively charged as a whole. But I am inclined to think that it is more likely that the earth is one of the coats of a compact Leyden jar, with the upper atmosphere as the other coat; and that the lines of force from the earth do not to any great extent penetrate into the regions of space, or terminate—for they must terminate somewhere—on either the sun or some other planet.

The electric gradient in the atmosphere is normally positive downwards, but there may be a reversal in bad weather, a reversal before rain. We also sometimes get the reverse effect of dust and mist; before a dust cloud or before any wind containing solid or liquid particles we may get a reversal of the normal atmospheric charge. I suppose that that is due to something like friction, the generation of frictional electricity. But I have an open mind on nearly all these problems connected with atmospheric electricity because there are people now who study them more closely than I have been able to. Dr. Chree and Dr. Glazebrook, for instance, and others no doubt who are connected with Observatories, who have more recent knowledge of these matters; and theories must be given by those who are specially working on these lines.

I should like to read some of the early statements by Lord Kelvin on this subject. In the year 1856 he writes from Creuznach to his brother: "I have become acquainted with a Mr. Dellmann here, who makes electrical observations for the Prussian Government. I have seen his mode of observation of atmospheric electricity which is very simple. There is always an effect of one kind indicating negative electrification of the earth's surface, but when the sky is much overcast there is little or none"; and that becomes important later on. There is this gradient of potential on a fine day, but on a cloudy day much less—"little or none" he says. "Detached clouds alter the effect quickly, sometimes give a great amount of reverse effect, and the first drops of a shower generally do so. I am having an electrometer of Mr. Dellmann's construction made." "The earth's surface is always found negative"—that is after he had made a lot of experiments—"day and night after fair weather, and only occasionally positive in broken weather or during an actual fall of rain in the immediate neighbourhood." Later on he speaks of observing many times, from May till September, 1859, with his portable electrometer in the Isle of Arran at Brodick Bay. "In ordinary fair weather I found the difference of potential between the earth and an insulated burning match at a height of 9 ft. above it to vary from 200 to 400 Daniell cells or, as we now say, volts."

(It is rather interesting, this introduction of the familiar term "volts." It is interesting to me to know that in my lifetime ohms and volts and amperes took their birth. So did the whole C.G.S. system of measurement. We are all now so familiar with these units that it is difficult to believe they are not mentioned in the Book of Genesis; but they are comparatively recent innovations. I remember a very long time ago that as a unit of resistance we used to employ 70 ft. of No. 16 common bell wire. That was specified as somewhere about an ohm. The term "ohm" was certainly used before the others, but it was extremely difficult at that time to get into the heads of students, including myself, the way in which an ohm was really defined and measured, in absolute measure; especially as Lord Kelvin insisted, to my mind quite wrongly, that a resistance was really a velocity. My recollection is clear that the ohm came first, a long time first, and was defined as an earth-quadrant per second, or 10^9 C.G.S. units of velocity. It is really μ times a velocity. It is handy to remember that μ times the velocity of light is 30 ohms. That is an accurate statement of fact, except in so far as refined measurement may affect decimal places in the number 30, which cannot possibly be exactly 30 but must be incommensurable. The volt came next, and was defined so as to be of the same order of magnitude as the Daniell cell, which had been previously employed as the unit. Accordingly it became 1/300th of an electrostatic unit, or 10^8 C.G.S. magnetic units. The ampere naturally followed; with the inconvenience that it had to be one-tenth of a C.G.S. unit instead of a whole unit. Then came the watt, bringing us back to straightforward mechanics, without any unknown or etherial constants, and being equal to 10 million C.G.S. units of energy per second.)

Lord Kelvin usually found a potential of 200 or 400 volts for a 9-ft. elevation. Sometimes it rose to 3,000 or 4,000 volts with an east wind. He says that in fair weather he never found the potential other than positive, and later on he says: "*The common fair weather condition I am forced to conclude is due to a paramount influence of positive electricity in higher regions of the air.*"

Now, I have put the above sentence in italics because I want to emphasize it as at any rate Lord Kelvin's opinion at that time. It is a moot point with me, and I believe with everybody, as to which is cause and which is effect in the changes of weather and the changes in sign of atmospheric electricity. It is certain that when the weather breaks up, the gradient changes and may be reversed in sign; but whether the break-up of the weather is the cause of the reversal of the potential, or vice versa, I do not know. Anyhow here Lord Kelvin considers that the fair-weather condition is due to positive electricity in the higher regions of the air, notwithstanding the negative electrification of air in the lower stratum near the earth's surface. Air close to the earth's surface is commonly negative. If a window of a room is opened and air allowed to come in, it will commonly be found to be negatively electrified. That is natural enough, because it has been receiving some electricity from points and edges on the negatively charged earth.

At a lecture at the Royal Institution in 1860 Lord Kelvin says: "If when the rain has ceased strong positive electricity obtains, it is a sign that the weather will continue fair for several days. If the electricity is but small, it is a sign that such weather will not last so much as that whole day, and that it will soon be cloudy again, or even will again rain."

With regard to the "electricity of clearing weather," if the clear weather is due to the electricity, as I venture to say I hope it is—it is very wrong to hope for things in science, I know, but I have a kind of hope that that is the case, and it will be seen why—we may imagine that we can acquire some control over the electrification of the atmosphere, and thereby and to that extent there would seem to be a feasible method of beginning a control of the weather—at least if the one is due to the other in the way that is here suggested.

There used to be some incredulity as to whether air or gases could really be electrified. It used to be thought—indeed I have heard Lord Kelvin himself say sometimes rather tentatively—that when we apparently electrify air, as for instance from a point, we were really only electrifying the dust—either dust given off from the point, or dust already in the air, of which there is always plenty. He doubted at that time—at any rate for a short time—whether atoms themselves could be electrified. He ultimately satisfied himself that they could, by an argument which Professor Elihu Thomson also used, to this effect: Imagine a charged sphere of water, a charged raindrop, for instance; let that raindrop evaporate; the evaporation carries off no charge. That has been completely proved, that the evaporation of vapour from a charged surface does not carry off any of the charge; the molecules that go away from the surface do not act as proof-planes. Evaporation then leaves the charge what it was, but the globule is getting smaller and smaller, till it disappears; and when it has gone the charge must remain in the vapour or in the air.

That was the argument. But the argument is not conclusive, for, as we know, Mr. Aitken of Edinburgh showed that there was a nucleus of dust necessary for the condensation of aqueous vapour. There would therefore be a dust nucleus, though a very minute, perhaps an ultra-microscopic one, at the centre of every raindrop; and that little dust particle, it might be, which went off with the charge. Hence I say I do not think that argument fully substantiates the true electrification of an atom. But now, owing to the researches of Mr. C. T. R. Wilson and others, we know that there are other nuclei than dust particles which act as centres of condensation for water vapour; we know that nuclei can be called into existence by Röntgen rays, uranium rays, and ultra-violet light; that positive and negative ions differ only in their power of condensing water vapour, and that a cloud may form round either, though it forms more easily round the negative kind. And Sir J. J. Thomson has pointed out* that in consequence of this difference, when cloud particles fall under gravity electrical separation may take place. It is found by Wilson that there really is such a difference, the negative ions condensing water at a less super-saturation than positive ions require, and so tending to be carried downward and separated from the positive.

Again, there is the effect of light on electrified surfaces. Ultra-violet light falling upon a charged clean zinc surface, and indeed upon many another kind of surface, enables it to give off negative electricity freely. It emits electrons, I suppose, under the stimulus of the light waves; in fact, there is no question that it does. The discharge of electricity under the action of ultra-violet light is well known. I have found that leaves of trees and leaves of plants are very efficient givers-off of a charge under the action of ultra-violet light. (I made a lot of experiments of this kind while I was at Liverpool, and have the record of them, but it was never published.) Now, inasmuch as the surface of the earth is charged negatively, and inasmuch as it is exposed to ultra-violet light from the sun, it is manifest that the layer of atmosphere near the earth will get negatively charged. The lower air must be more or less negatively electrified with the same kind of electricity as that of the earth's surface, and since the tension reaches a high degree of intensity at every tree-top and pointed vegetable fibre, it must always cause more or less the phenomenon which becomes conspicuous as St. Elmo's fire. Hence in fair weather the lower air must be negative, although the atmospheric potential even close to the earth's surface is still generally positive. But a considerable area of this lower negatively-electrified stratum is carried up over any locality by wind blowing inwards from different directions; its effect may for a time predominate and give rise to a negative potential in the air and a positive electrification of the earth's surface. Moreover, and still more if it is churned up by a horizontal cyclone, the upper positive stratum and the lower negative stratum may get mixed to some extent with each other, and we may obtain the conditions for a discharge from the negative into the positive, that is, the conditions for a thunderstorm. I cannot but think that one cause of atmospheric electricity of the violent kind is due first to the influence of ultra-violet light in coaxing away some of the earth's negative charge into the air, and secondly to the wind, the revolving wind which accompanies or is associated with a thunderstorm, often a horizontal cyclone, churning these up, bringing them near one another, sufficiently near, within half a mile or so, for some flashes to take place.

It is almost a proverb that an English summer consists

* *Philosophical Magazine*, vol. 46 (Series 5), p. 528, 1898.

of two fine days and a thunderstorm, and although that is an exaggeration, yet one is familiar with the fact that after a good spell of sunshine we are very apt to find it finish off with a thunderstorm. I cannot but think that the two are connected, and I should imagine that over the sea or over the desert, where there must be less emission of negative electricity, the prevalence of thunderstorms would be less.

The next slide is intended really to show that the leaves of plants—a large number of different plants are here depicted—are by their shape well calculated to discharge electricity into the air. They are all pointed and serrated, some more than others, but on the whole one could not imagine a conductor of that kind holding its charge very well. It would appear as if they were intended to get rid of their electricity. And if that condition has been brought about by evolution it must be for some definite reason, presumably for the good of the plant. I want to emphasize that point, because if it is for the good of the plants that they should discharge electricity—that there should be a current up through the leaf—then it may be possible, by the artificial increase of the potential gradient above the earth, to increase this stimulus, to assist the electrical massage or whatever is happening in the plant, to stimulate the natural processes by means of electrification. We must admit that from the shape of the leaves it is evidently suggested, on the principle of evolution, that such discharge of electricity is beneficial.

That sunlight assists this action is familiar, no doubt, and I will just remind members of a simple experiment. We have here an arc-light lantern with quartz lenses and a quartz prism (because glass is very opaque to ultra-violet light) arranged so that the spectrum can be seen. If we take a charged electroscope with a clean piece of zinc attached to it, and then move the piece of zinc until it is plunged into the invisible short-wave radiation, the maximum effect will be observed and the leaves collapse very rapidly, showing that under that stimulus the metals, like leaves, or indeed many surfaces—not all—get rid of their electricity, especially negative electricity, freely.

I have said that that action is probably associated with the production of thunderstorms, and although I am not dealing with the lightning aspect of atmospheric electricity to any great extent, yet I have some slides of lightning flashes, photographed by different people, which I will run quickly through the lantern, because some of them are rather striking and beautiful, though no doubt they are fairly familiar.

This flash shows the side flashes. It negatives the idea that a lightning flash is one definite thing and that if it strikes one place all other places are protected. A lightning conductor receives the main flash, but there are all these branch flashes which, though weaker than the main flash, are not by any means to be despised.

The next slide does not show a lightning flash, but an experiment—made by my assistant, Mr. Robinson, when we were investigating lightning—of sending a spark through rain. We had an artificial rain shower in the laboratory. We wanted to see how it was that it was possible to get such an enormous length of spark, and we found that through raindrops we could get a very great length of spark from an ordinary Voss machine. This represents a laboratory lightning flash assisted by artificial rain.

The next slide shows a real lightning flash tying itself up into knots in the most extraordinary way, and I presume doing so because it is dodging about from one raindrop to the next. It does not care particularly which way it goes, but it takes any raindrop that it happens to find within range, whether such drop is in a straight line towards the earth, or to the cloud, or in any other way. Of course a good deal of that apparent return upon itself must be merely foreshortening; but still the irregular path is remarkable. It does not know that a straight line is the shortest distance between two points.

Here is a photograph taken by my assistant when he was attending a football match, because he saw there rather a remarkable occurrence, which I will venture to bring to the notice of this audience. A great metal roof supported by iron stanchions will be seen. There was a thunderstorm going on at the time and the building was not struck, but a youth was leaning against one of the metal posts. There must have been a charge in the roof area produced by induction, a static charge, which was liberated by some flash—"Lord Mahon's returning stroke," as Tyndall used to call it. The charged area then discharging down this pillar, and no doubt also down the others, gave the young fellow who was leaning against it a shock which precipitated him violently into the midst of the crowd in front, causing a sensation and making the people think he was killed. He was astonished and "shocked," but not damaged. I mention this case as one that came under skilled observation. It actually occurred at the time of a neighbouring flash. The metal conductor, against which the youth was leaning was no doubt earthed —one would expect it to be much better earthed than a man standing on a form and leaning against it could be; but it is only characteristic of what happens. These side flashes indicate how high the potential may be for these sudden rushes of electricity; they demonstrate that one cannot lean against lightning conductors with impunity. There have been distinguished Presidents of this Institution who have thought otherwise, but I do not think on experimental grounds.

Here are a number of multiple flashes showing a complete rot in the air. If it gives way at one point it gives way at a large number of points, because the air becomes conducting, as it does in a vacuum directly the discharge begins.

Next we have one of the regular stock pictures of the aurora borealis, showing that curious fringe or curtain effect, which I only show here for comparison with the next photograph, which shows the banded effect of a lightning flash. The appearance of that lightning flash, showing a broad ribbon-like band, is not due to movement of the camera. I assume it to be due to the blowing away of the aura from the main discharge. It is presumably going sideways down the wind, but is still sufficiently bright to leave an impression on the plate. Perhaps some of those present have a better theory of those effects, which do sometimes occur and which remind one of the curtain effect of the aurora. The dark part of a flash appears to be only a photographic effect, a well-known effect of overexposure. But as regards the constitution of the aurora, which undoubtedly is a subject of electrical interest, it will be convenient to quote here for future reference a paragraph from an article by Dr. Fournier d'Albe in the *English Mechanic* for 19th May, 1911.

Spectrum of the Aurora.

"In 1906 Störmer published in a Swedish journal a paper 'On the Trajectories of Electric Corpuscles in Space under the Influence of Terrestrial Magnetism, applied to the Aurora Borealis and to Magnetic Disturbances.' He therein showed, by calculations and models, that the aurora is due to electrons projected by the sun and bent round upon the dark side of the earth by the earth's magnetic field. This has recently been confirmed by the stereoscopic photographs taken by Norwegian expeditions organized by Birkeland. The most striking thing about these electrons is their extraordinary speed, which differs by less than 1/10th of one per cent from the velocity of light itself.

"According to observations made in vacuum tubes, air becomes opaque to cathode rays when its pressure attains 0·1 mm. of mercury. This happens at a height of 37 miles. That, therefore, is the limit of auroral displays, and it is significant that the most reliable observations—those of "draperies"—give that height as the inferior limit. The highest auroras are the steady, homogeneous arches, in which no waving or coruscating action is discernible. Paulsen and La Cour endeavoured to determine their elevation by theodolite, but found them too high for accurate measurement. They cannot have been lower than 250 or 300 miles.

"Now, it is well to remember that the radiating aurora owes its light mainly to nitrogen. The violet light is chiefly due to the line 391. The red light which sometimes shines out is composed of the lines 631 and 519, both of which belong to the anode spectrum of nitrogen. Of the hydrogen lines, the one at 486 is established beyond a doubt. Those at 656, 410, and 434 are more or less doubtful. The following comparison between the top and bottom of the same auroral structure is due to Carlheim-Gyllenskjöld. It distinctly shows the decrease of nitrogen and increase of hydrogen with increasing height:—

Spectrum	Number of Lines Top	Bottom
Air spectrum	9	8
Nitrogen, anode spectrum... ...	2	4
Nitrogen, cathode spectrum ...	10	14
Hydrogen spectrum	3	1
Unknown	8	4

The helium line, 502, is suggested by the lines imperfectly observed at 500 and 505.

"The greatest controversy still rages about the chief auroral line, 557. This was observed most unmistakably by La Cour and Paulsen. This value differs considerably from that of the chief line of the solar coronium, whose position is 532·7. Nevertheless, this must not be taken as proving that coronium and the auroral gas are different, more especially as the corona owes its luminosity to temperature, whereas the aurora owes it to electric discharges. It is possible that an atmosphere of a gas provisionally called 'geo-coronium' is productive of the Zodiacal Light, and the observed irregularities of the latter are another point of analogy with the solar corona."

Causes of the Earth's Electrification.

Now I want to say a word about the causes of the earth's electrification, the causes of natural atmospheric electricity. I must be very brief on this point. Many suggestions have been made as to the splashing of water, the evaporation or condensation and falling of rain, and other effects of that kind, but I myself am in favour of a cosmic cause rather than a local cause. I think it must be largely or mainly due to particles coming from the sun. The sun is a charged body. We know by the investigations of sunspots that there are crowds of electrons there causing a magnetic condition. We know it can produce magnetic storms on the earth when one of its ejected torrents of electrons comes anywhere near us. At any rate that is the way I think of it. And we know that a hot body gives off electricity—electric evaporation as Professor O. W. Richardson called it the other day in his Inaugural Lecture at King's College. The sun must give off alpha and beta rays; and when these come near the earth the beta rays, the electrons, the negatively charged bodies, are entangled as it were in the earth's lines of force and conducted to the poles, conducted on the whole spirally round the earth's lines of force into the Arctic and Antarctic regions, being easily deflected by a magnetic field.

The alpha particles, the positively charged bodies, are not so easily deflected. They are barely deflected at all, and therefore will come down with the sunshine mainly into the tropics. I take it therefore that the equatorial regions of the earth or the earth's atmosphere are liable to receive a good deal of the positive solar emission, and that the polar regions are liable to receive the electrons, which no doubt are responsible for most of the aurora; and then I suppose these charges re-unite as best they can, by earth currents or other ways, through the crust of the earth or through the atmosphere. That I think is what mainly accounts for the upper positive charge of the earth's atmosphere. Also the earth's atmosphere is ionized and rain brings down the negative electricity, leaving the positive up there. That is another cause.

But the ionization: What is that due to? Well, alpha rays ionize air, and gamma rays ionize air; gamma rays are very penetrating and may ionize the lower stratum, while the other rays would act usually in the upper regions. An ionized atmosphere conducts, hence there must be a downward current. If there is a positive gradient there must be a downward current, and the amount of that current can be estimated; roughly speaking, the ordinary fine weather gradient is one volt per centimetre. It may vary a good deal, but roughly that is the order of magnitude, one volt per centimetre. The downward current ordinarily is about one micro-ampere per square kilometre; an exceedingly small current, because of course the air is very nearly an insulator. The main effect in the atmosphere is the potential gradient; a very minor effect is the current which is continually flowing down.

In the upper layers the conductivity is of course far greater. Undoubtedly, rarefied air conducts, and it must be because it is ionized. There is a pressure at which the conductivity reaches a maximum; that pressure must exist in the upper atmosphere. Accordingly there must be a good conducting layer round the earth. If it consisted of electrons it would be opaque, but if it consists of electrolytic ions it need not be. We know that negative ions are slightly more mobile than positive ions in any

case, especially at reduced pressures, but their mobility is not of a different order of magnitude, as it would be if they were electrons.

Here is a diagram (Fig. 2) prepared by M. Langevin, showing the mobility of atmospheric ions, both positive

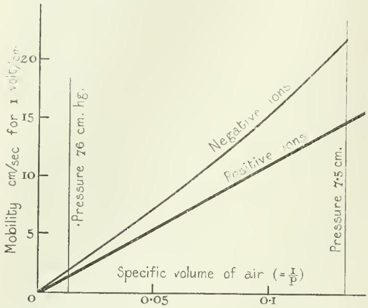


FIG. 2.—Mobility of Atmospheric Ions (Langevin).

and negative, at different pressures; and the conductivity of course depends on the mobility. The mobility was measured by him, under a gradient of a known number of volts per centimetre, by the device of driving them back by means of an air blast, and so neutralizing their motion, and measuring the speed of the blast necessary to check the current. The results are plotted not with regard to pressure, but with regard to inverse pressure, so as to show readily the inverse proportionality between pressure and mobility. Hence the conductivity, which depends on the mobility and the concentration together, seems to be fairly independent of the pressure for a given amount of ionization. But of course the ionization at different levels is not constant, and a great deal more has to be ascertained about the effective conductivity of the upper atmosphere.

But it may be said that conductors ought to be opaque, and if the air is a conductor how can it possibly be transparent? Well, this question of opacity is one which I have written on in the *Philosophical Magazine* not long ago (June, 1913).* There are different kinds of opacity in the atmosphere, which are observed in connection with wireless telegraphy, and there are certain kinds of opacity which affect long waves but do not affect short waves. We are familiar with that kind of conductivity in liquids. A liquid screen could be fairly opaque—a thick screen of dilute sulphuric acid would be fairly opaque—to Hertz waves, but it is transparent to light. Electrolytes need not be opaque to the slight and excessively rapid quiverings which constitute light; these appear to be able to get through an electrolytic conductor without much waste. But with steady currents—and long waves of course approach steady currents rather more than rapid vibrations do—the conductivity becomes effective. The ionic carriers in the case of electrolytes are comparatively heavy things, molecules or perhaps molecular aggregates. In metals the conveyer of electricity is the electron, and that is affected even by light waves, and so metals are opaque to every kind of wave.

But what about the atmosphere? Little is known about the upper atmosphere. It is remarkable how we live here and know so little about the atmosphere above our heads and about the ground beneath our feet. We explore the surface; we penetrate the crust to about a mile for commercial purposes; we penetrate the earth's atmosphere to about five miles or thereabouts—possibly now as much as nine miles. I think that further vertical exploration is wanted. We have nearly exhausted the surface of the earth now that the poles have been more or less conquered, but "up" and "down" seem to want further exploration. I expect that that will some day be undertaken. To quote Dr. Fournier d'Albe again:

"Already some progress has been made. It is now thought by many meteorologists that the earth is surrounded by successive shells of different physical and chemical constitution. The crust of the earth is no longer clothed in a gaseous envelope of uniform composition, merging insensibly and steadily into the interstellar ether. There are at least two atmospheric skins, and at the present rate of progress our resemblance to an onion will soon become quite obvious.

"The manner in which this change of views has been brought about is instructive. It began with the *ballons sondes*, small free balloons provided with registering apparatus, sent up by M. Teisserenc de Bort from his observatory at Trappes, near Paris, in 1901. He, and Assmann in Germany, shortly afterwards, found that after a certain height is passed—it ranges from 23,000 to 36,000 ft.—the thermometer ceases to fall on rising further into the air. It stands at $-67°$ F., and stops there."

References to this part of the subject are as follows:—

A. WEGENER. "Untersuchungen über die Natur der obersten Atmosphärenschichten." *Physikalische Zeitschrift*, vol. 12, pp. 170 and 214, 1911.

J. DEWAR. *Presidential Address to the British Association*, 1902.

Also "Problems of the Atmosphere." *Proceedings of the Royal Institution*, vol 17, p. 223, 1902.

HANN. "Composition of the Upper Air." *Meteorologische Zeitschrift*, p. 122, 1903.

JEANS. "The Upper Atmosphere." *Bulletin of the Mount Weather Observatory*, vol. 11, p. 374, 1910.

[Since the Lecture was delivered the following note has appeared in *Nature* for 12th February, 1914, page 666:—"Information has been received that through the generosity of Mrs. Rotch, the observatory at Blue Hill, near Boston, founded by the late Professor Lawrence Rotch, for the study of the upper air, and partially endowed by his bequest of fifty thousand dollars, has been established for five years in connection with Harvard College. Mr. McAdie, formerly in charge of the Californian section of the United States Weather Bureau, has been appointed director of the observatory, and at the same time professor of dynamical meteorology in Harvard University. We also understand that provision is to be made in connection with the French Department of War for continuing the aërological

* SIR O. LODGE. "On a Dynamo for maintaining Electrical Vibrations of High Frequency, with Some Notes on the Transmission of Waves in Wireless Telegraphy." *Philosophical Magazine*, vol. 25 (Series 6), p. 757, 1913.

work carried on by the late M. Léon Teisserenc de Bort, at his observatory at Trappes."

But it is not easy to explore the upper atmosphere. The best method hitherto has been kites. Kites carrying meteorological instruments have certainly been made to fly to considerable heights, and the French have, as said above, sent up their *ballons sondes* still further, and discovered the isothermal layer. But there is a handy method of exploring the atmosphere further, by means of Hertzian waves. It is familiar how in wireless telegraphy the distance to which Hertz waves penetrate is much greater than would have been expected. There is something that assists them round the curvature of the earth ; I cannot but feel, and Dr. Eccles among others has worked out an ingenious theory, that the upper air contributes a good deal to this effect—the conductivity, the ionization of the upper air.

It is a fact that wireless waves curve part way round the earth ; but what is the reason of their curving round ? Waves should be sent up for the purposes of experiment, with the object of finding out the conditions under which they are reflected or transmitted or refracted or totally reflected, or whatever happens to them ; because it is a point worthy of investigation. A Committee of the British Association is now constituted for the purpose of requesting aid from different wireless stations, and from observers generally, in obtaining records which shall after analysis give us some idea of what is happening to the waves in the very upper regions of the air. My paper in the *Philosophical Magazine* for June, 1913, discusses some of these phenomena and the influence of sunshine.

Another method of studying the upper air is by means of explosions. I quote the following from Dr. Fournier d'Albe.

Reflection of Sound.

"Some very remarkable conclusions have been arrived at from the study of loud explosions, such as the dynamite explosion at Förde (Westphalia) in 1904, the roburite explosion at Witten-Annen in 1907, and especially the dynamite explosion on the Jungfrau railway on the 15th November, 1908. This was studied by De Quervain, who drew some maps indicating the range of audibility of the explosion. These maps show that it was heard in the ordinary way for 19 miles round. Then followed the 'zone of silence,' about 60 miles across, and then a range of abnormal audibility extending for another 30 miles. A calculation, undertaken by Von dem Borne, shows that the abnormal audibility is fully accounted for by total reflection from a hydrogen atmosphere at a height of 47 miles. On account of the fall of temperature with height, there is a gradual bending of the sound-waves (as of light-waves in the mirage), but there is a certain minimum distance within which the sound-waves can possibly strike the earth after reflection, and that distance is 72 miles, which agrees very well with observation. To get this minimum range, the sound-waves must pass upwards from the ground at an angle of 30°. Any greater or less elevation gives a longer range.

"It appears quite likely that the study of explosions will form a valuable addition to our means of investigating the upper atmosphere."

Dr. Wegener of Marburg has attempted to prognosticate a good deal about the condition of the upper atmosphere. Fig. 3 is Dr. Wegener's diagram of the atmosphere to an enormous height. A great deal of it I should think is necessarily speculative, but still it represents an expert opinion.

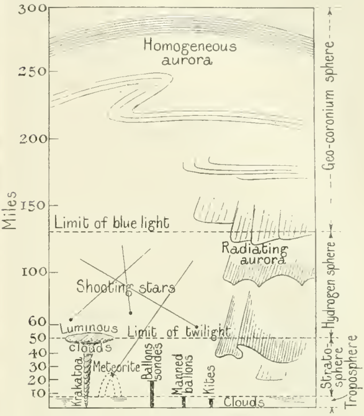


FIG. 3.—Cross-section of the Atmosphere (after Wegener).

Further information about the condition of the upper air, and recognized methods of examining it, can be obtained from a recent book, entitled "The Structure of the Atmosphere in Clear Weather : a Study of Soundings with Pilot Balloons," by C. J. P. Cave, M.A. (Cambridge University Press) ; which book was reviewed by Dr. W. N. Shaw in *Nature* of 18th September, 1913. The following quotations from this review will show that parts of the above diagram (Fig. 3) convey orthodox teaching.

"The investigation of the upper air is of such interest and the incidental problems which it presents are so numerous, so attractive, and, in these days of flying, so practical, that it is a matter of some surprise that there are not found more men of leisure to follow the notable examples of Professor Lawrence Rotch and M. Teisserenc de Bort in the investigation of the free atmosphere. . . . We have had to chronicle the division of the atmosphere into two distinct layers, an upper layer, the stratosphere, in which there is little or no variation of temperature in the vertical, but sensible variation from day to day, or along the horizontal, and a lower layer, the troposphere, in which the variation of temperature is greatest in the vertical and relatively small along the horizontal. . . . Ten kilometres may be taken as a rough and ready estimate of the average thickness of the troposphere with the understanding that there is a latitude of three or more kilometres to be allowed in either direction according to circumstances. . . .

"For the practical study of the dynamics of the atmosphere we are largely dependent upon observations with pilot balloons. They may be taken as supplementing

observations of clouds, and, in due time, both must be brought into relation with the observations of pressure and temperature obtained from registering balloons. It is in many ways unfortunate that the track of a registering balloon cannot always be followed by a theodolite or otherwise determined."

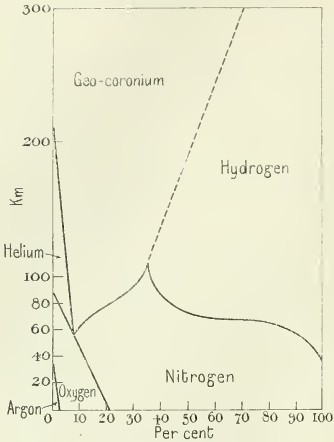


Fig. 4.—Percentage Composition of the Atmosphere at Various Heights (after Wegener).

On a similar scale of height Fig. 4 is Wegener's diagram of the chemical constitution of the atmosphere at different elevations. It illustrates what he supposes the percentage composition of the atmosphere to be at various heights. At the height of 20 miles, for instance, he depicts about 1 per cent of argon, 14 per cent of oxygen, and say 85 per cent of nitrogen. At a height of 100 miles he considers that there is practically no oxygen, about 4 per cent of helium, about the same amount of nitrogen, a great deal of hydrogen, and some of the speculative gas which he calls geo-coronium—of constitution akin to the material in the corona of the sun which gives the coronium line in the spectrum. The diagram, of course, only represents percentages, not actual amounts. The actual amount of the lighter gases must anyhow be exceedingly small.

It must also be understood that I do not vouch for their presence at all in any appreciable quantity. I see many reasons against it. The amount of hydrogen, for instance, must depend on the rate of supply, *e.g.* from volcanoes, and the rate of escape. The latter datum, on Dr. Johnstone Stoney's theory, is more definitely known than the former. Stray wisps of perhaps frozen gases may exist, orbitally moving through space, and the earth may pick up not merely stones, iron fragments, and dust—but other sometimes less innocuous things, as indeed Lord Kelvin once suggested—a line of thought which the strange occurrences of new diseases from time to time must do something frequently to stimulate.

Artificial Electrification.

I must go on to the subject of artificial interference with atmospheric electricity. In 1883 and 1884 I was investigating dust and its electrification, and I gave a demonstration at a meeting of the British Association at Montreal—where Lord Kelvin was present and was very enthusiastic about it, as he always was for any new experiment—showing the effect of electrification on dusty or smoky air. The particles aggregated together into a kind of visible lumps or snow—cohering somewhat as iron filings do near a magnet—and fell or were deposited upon the surface. The experiment has become so familiar that I shall not show it, but I want to emphasize the fact, also exhibited at the same time, that not only solid dust shows this effect, but liquid dust, that is to say, a cloud of visible steam. If a discharge is passed from a point into a bell-jar full of "steam" from a kettle the drops coalesce; they coalesce together and rain is obtained. The microscopic globules become bigger and they can be seen falling as a Scotch mist.

Strange though it may seem in this country, most of the countries in the world suffer more from drought than from too much moisture, and would benefit by being able to produce rain. If there are no clouds it must be hopeless; but it is said to be irritating, in a place where they want rain, to see clouds assemble and then disperse without any water falling. If it were wanted at that time to cause rain, I take it that by ascending a mountain and flying a kite—or perhaps a kite alone would be sufficient to reach the lower clouds—and by discharging sufficient electricity into those clouds, I cannot but suppose that the drops would behave there as they do in the laboratory, and that at any rate some of them might be stimulated to coalesce and to fall; and I imagine that when once the process had begun it might spread and that a real rain shower might be obtained. There are many questions about that, as to the amount of energy and so on. I feel, however, that it is a matter for experiment, and that until one has experimented on a large scale one cannot tell what will happen. I must confess that this lecture is not a record of achievement but is rather a programme of agenda.

I think that those experiments ought to be tried, and that we cannot tell what will happen until we do try them. But they will be expensive, because it is no use trying the thing on a laboratory scale when we are dealing with the forces of Nature; we must cope with them, and we must expend a certain amount of money and invest a certain amount of capital in doing it.

But what about the best mode of supplying electricity for this purpose? The old method is by the static machine, the convective machine, the Holtz, the Voss machine, or the Wimshurst. It is surprising that no kind of static machine has been taken up by engineers and made practically efficient. I think I am right in saying that, although there have been decided improvements; but I take it that such machines will always be rather inefficient in the matter of strength of current, because the current at one part has to be carried by mechanical motion, and the current that can be carried by the few electrons that constitute an ordinary static charge, with the rapidity of any

feasible mechanical motion, is extremely small as compared with what can be carried by the immense crowd of electrons in a metallic conductor. Practically the quantity that can be set going in that way, mechanically, is very minute as compared with what can be driven by a dynamo.

Then there is the chemical method—the ions in liquid, the battery method, the voltaic method; and it may be that a very large battery with a very large number of cells may be adapted to this purpose—a utilization of the ionic procession in liquids. The difficulty now is not the quantity: there is plenty of quantity: the difficulty is to get sufficient potential. The same thing must be said of a dynamo. There we have an electronic procession in the metal. There is no difficulty about its speed or strength of current, but great difficulty about the insulation when the voltage is high. The method which I have found best so far has been the method of a transformer and valves. We transform up to any required potential, and then bank up the electricity that is supplied by means of electric valves.

To this audience I need hardly explain the meaning of an electric valve. It is a device which transmits electricity in one direction only, so that up to a certain limit it is passed through easily and is prevented from coming back again—exactly like a valve. In that way a Leyden jar can be permanently charged by connecting it with an induction coil, although it is short-circuited by the secondary winding, and can remain so, when a valve has been inserted. Charges are put into it intermittently, and after the manner of a water-ram they pile themselves up until they cause the jar to overflow; valves bank up the charge, as it were. Here is an arrangement by which an alternating dynamo can be used to charge one conductor negatively, which may be earthed, and another conductor positively, which may be taken up into the upper atmosphere. It is an ordinary arrangement with four valves, or four sets of valves.

I might show the detail of the valves themselves, but I have published this in the *Philosophical Magazine*,* and I will not take time over it now.

This slide shows a view of them. They have a very large and open cathode and a very small and constricted anode. That is not all that can be said about them, but that is the basis of them.

Here is an arrangement for supplying high-tension electricity where it is wanted for any particular purpose. If excessive potential is required a row of valves is needed, because although they each bank it up, yet they can be burst back, so to speak. If an enormous potential is wanted it is necessary to have a series of them.

Electrification of Crops.

In the matter of electrification applied to horticulture and agriculture Lemström is one of the pioneers. Lemström† experimented ever since 1885 on the influence of artificial electric fields or currents on the growth of plants. The influence is, he says, in general highly beneficial; for instance, it shortens the time required by strawberries and raspberries to ripen, and increases the yield. It may, however, be injurious, especially during bright days, unless abundance of water is provided. Lemström believes atmospheric electricity plays an important part in the growth of vegetation in high latitudes, and he assigns a special rôle to the needles of fir and pine-trees. E. H. Cook* describes experiments somewhat similar to those of Lemström. He observed a beneficial effect on plants grown under a pole—especially the negative pole—of a Wimshurst machine or an induction coil. Cook refers to experiments aiming at the direct utilization of atmospheric electricity.

Now the valves that I have been speaking of afford a method of applying high-tension electricity in a more engineering way than hitherto, and to some of this work in agriculture they have been applied by the Agricultural Electric Discharge Company of Gloucester.

The slide shows a practical instalment in a shed for the purpose of electrifying the atmosphere; it is as supplied for agricultural purposes for electrifying crops. The wire from them goes out into the field, through a very elaborate insulator. An overflow or emergency spark-gap serves to measure the potential of the conductor. It is not generally actually sparking, but it can be made to spark by turning a handle so as to diminish the gap, just to see if sufficient potential is maintained, and that there is not too much leak on the conductors out of doors. The spark-gap acts as a sort of safety valve too. The wires are supported on posts by very special insulators provided with an oil cup to withstand these high potentials. The wires which are suspended over the field are not attached to the main insulator at all, except through ebonite rods or looped porcelain insulators. There are various devices for assisting the insulation.

In a field near Bevington, in Worcestershire, where this method has been applied to the electrification of crops, wheat has been grown under wires stretched on poles. About 1 pole to the acre suffices, or say 70 yards apart. It began in 1906, and the effect in nearly all the years has been a decided increase, I am told, except in 1911, when the electrified plot and the control plot both gave about equal amounts. There was drought that year; it was an exceptionally bright year, and there was plenty of sunshine. That is what I think our experience leads us to hold, that the electrification supplements the sunshine and is most required when the sun is feeble. When the days are overcast that is the time when they require a stimulus, but if the sun is particularly bright then by supplying positive electricity artificially also we should be over-stimulating the crops.

The gradient of potential artificially supplied is the fine-weather gradient. It has to increase the downward current. It will be remembered that the natural downward current is extremely small—about one micro-ampere per square kilometre, but artificially we can get it to 10,000 times as much in some cases. Even so the current downwards is extremely small. I think the effect must be due to the charge rather than to the current. It may have some nitrogenous manuring effect, but it can hardly supply an appreciable quantity of extra energy.

The wires supported by the poles can be high enough not to interfere with agricultural operations. What we

* Sir O. Lodge. "The Mode of Conduction in Gases, illustrated by the Behaviour of Electric Vacuum Valves." *Philosophical Magazine*, vol. 22 (Series 6), p. 1, 1911.

† S. Lemström. "Experiments on the Influence of Electricity on Plants." *Report of the British Association for the Advancement of Science*, 1898, p. 808.

* E. H. Cook. "The Action of Electricity upon Plants." *Report of the British Association for the Advancement of Science*, 1898, p. 809.

use are thick wires from pole to pole and then a number of quite thin wires across between the thick ones. We do not use points because we find that points screen each other, and they are not necessary if a thin enough wire is used. Cotton-covered wire discharges singularly well, except in wet weather; and in wet weather, or in weather in which the electricity is most required, the difficulties of insulation are naturally greatest.

Another difficulty is the screening of the control plots. We have an area under the wires and somewhere near it—as near as possible because we want the soil and conditions to be the same—we have another area not under the wires for purposes of comparison. But naturally enough it is found that the electricity which has been discharged from the system of wires blows down wind over the control plot, if it is in the direction of the wind, and tends to stimulate that plot unduly and to make them both virtually electrified. A farmer on whose ground the experiment is going on tells me that both the electrified and the unelectrified plots have given more than the average yield, but it does not make a good differential test. Screens are being erected to try and screen off the one from the other, but, as is doubtless known, it is not at all easy to screen atmospheric electricity: I have blown electrified air through fine-meshed wire gauze. At the same time a wire netting screen will to some extent protect the control area, especially near the screen, but at a distance the electrified air seems to go over or round, and we find a good deal of it down the wind, even at a distance. Professor Priestley of Leeds has called special attention to this fact.

As to the nature of the effect on plants, that is a botanical question which I am glad to know is being taken up by Prof. Priestley, Professor of Botany at Leeds University. He became interested in the experiments while he was at Bristol and has gone into the matter very thoroughly and has initiated experiments of his own. He makes certain suggestions about the possible ways in which the electrification may act, and points out that there are so many different things which may happen in a plant. In the *Annals of Botany* for January, 1914, there is a paper by him in conjunction with Mr. Knight "On the Respiration of Plants under Electrical Conditions." In a former paper he says*: "There are so many processes at work within the plant, of vital importance to it, which may be altered in quantity and quality by the application of electricity, that only laboratory investigations of an extensive kind can help us to understand the effect of placing a high-tension discharge above the plant, and of the resultant increase of the electric current through the plant to the ground. Thus in this country and elsewhere, at the present time, work is in progress upon the effect of such an electrical discharge upon the respiration of plants, on their synthesis of food, on the rate of evaporation of water-vapour from the leaf, and on many allied problems."

In the experiments which have so far been made, "The actual strength of discharge, as determined by the number of thin wires above the crop and the potential they are raised to, is not decided by experimentally determined necessities of the plant; the current supplied is that which proves most practically convenient. The sign of the discharge may be inadvisedly chosen. Positive discharge is used, but negative has never been adequately tried since the time of Lemström's experiments with far inferior apparatus."

I may conveniently add some further particulars recorded in the same article: "Experiments in both these branches of work are in progress at the University of Leeds—the laboratory work with the aid of a Lodge-Newman high-tension discharge apparatus, and the field experiments at the University experimental station, the Manor Farm, Garforth, where land has kindly been placed at my [Professor Priestley's] disposal by the courtesy of the Yorkshire Council for Agricultural Education."

Miss Dudgeon has also been conducting experiments at Dumfries, with the assistance of Mr. Cameron, the farmer on whose land at Lincluden Mains the crops are grown.

"Usually the overhead wire network itself consists of wire of two gauges (up till now galvanized iron wire has been used); the larger wire (No. 11) runs in two parallel strands across the strip to be electrified, and at every ten yards the thin (No. 24) wire spans the space between them, and from this wire, owing to its thinness, the high-tension discharge is continually leaking down to the plants beneath. As these wires will stand considerable strain, they can be drawn taut by means of the usual strainers, and as the poles stand some 16 ft. above the surface of the ground, the wires, in spite of their inevitable sag, remain well out of the way during all farming operations.

"The system of overhead wires is borne upon larch poles, crowned by specially constructed large insulators, in which the leakage, due to moisture condensed at the surface, is counteracted by an oil cup on the inner protected surface. The charged wires do not touch the insulators, but are suspended at some distance from them by means of some special insulating medium—rods of ebonite, chains of porcelain insulators, and other methods have at various times been used. If care is taken over this question of insulation, especially in obtaining adequate insulation where the high-tension wire leaves the shed and where the network is supported by the pole over the field, then it is possible to keep the overhead network continuously charged to very high tensions, such as 100,000 volts.

"In the various experiments carried out with this apparatus during the last seven years the potential of the overhead system employed, as measured at the spark-gap, has varied between some 60,000 volts and 100,000 volts."

That is the potential usually employed, between 60,000 and 100,000 volts. Of course the actual strength of the discharge may be varied, but we do not know sufficiently what the requirements of the plants are.

That is one of the difficulties in all these agricultural experiments, that they are so slow. There is no immediate response. We have to go through the whole season before we know that what we have been doing is correct; and when the farmer has found out that positive electrification gives him an increased yield it is difficult to get him to consent to an experiment with negative electrification. This is extremely natural: let it not be supposed that I am criticizing. On the contrary I wish to express admiration for the enterprizing and scientifically-minded farmers who have been good enough to allow experiments to go on on their lands. I wish specially to mention the local help

* J. H. PRIESTLEY. "Experiments in the Application of Electricity to Crop Production." *Journal of the Board of Agriculture*, vol. 20, p. 582, 1913.

of Mr. Bomford of Bevington Hall, Salford Priors, near Evesham, Worcestershire, in this way. The trouble caused must often have been considerable, in these early and experimental and small scale trials; for a 20 or 40-acre plot, though more than a laboratory experiment, is still a small scale trial. Not wheat only has been tried, but other crops, which will be referred to in their proper place. I am not at all sure, but I am inclined to think, that leguminous plants behave oddly in this connection: they seem to be quite as well satisfied with a negative electrification and do not care about the positive. One year we did have a negative electrification over wheat, by accident, in a place that was not properly controlled, and it was not a satisfactory year. On the whole I am inclined to think that the natural electrification of the atmosphere is what wants artificially intensifying at times; and certainly as far as the experiments go—those which my sons have been conducting with Mr. Newman—when this is done the crops are improved. Mr. Newman of Gloucester is the engineer of these operations; he has set them going and we have only supplied the apparatus for the high tension and supervised its working. They certainly find that the crops are improved. Strawberries, for instance, are earlier and also more plentiful.

It may be interesting to quote here some of the methods used for electrical measurements in this work. Dr. Priestley reports*:

"Suffice it to say that after trying several methods to obtain the required electrical measurements, the most practical and useful apparatus proved to be an electrometer with two different pairs of aluminium leaves giving a range of from about 80 to 800 volts. For determinations of atmospheric potential the electrometer was simply connected to a flame collector mounted on an ebonite stand; the electrometer itself stood on the field on a level glass plate, and care was taken that the insulated wire between electrometer and collector was not allowed to approach too close to any blades of grass.

"For the determination of the current density in the air a flame collector was replaced by a flat metal collector of known area and a condenser of known capacity connected up with the electrometer, the outer cases of both electrometer and condenser being connected to earth. The average time required for the electrometer to take its full charge and discharge to earth was then taken, and from these data, knowing the capacity of the whole system to be charged, it was possible to calculate the strength of the current per square centimetre at the point where the metal collector was placed in the air.

"When these data were obtained it was possible to compare the electric current in the field under the discharging wire with that present under the normal atmospheric conditions.

"This natural flow of positive electricity downwards through the air is of the order of 10^{-16} ampere per square centimetre. . . . In the conditions obtaining under the wires the current was increased to a value of from 10^{-12} to 10^{-11} ampere per square centimetre. That is to say, the current, under the electrical treatment, is raised to some 10,000 times its normal value.

". . . It is still a remarkably low figure, however, and suggests that if effect is produced by such treatment it is to be looked for in the more direct utilization of sources of energy already available, under the stimulating action of the electric current.

"As soon as the current under the wire had been determined, measurements of the current in other parts of the field at varying distance from the charged overhead wires were made. These determinations soon showed that the effect of the discharge could by no means be looked upon as restricted to the area under the wires, but that on a still day a current at least a thousand times the normal was to be found at a distance of some 30 to 40 yards out from the wires, while on a windy day, even though the wind was comparatively light, the current travelled out away from the wires down the wind for quite unexpectedly long distances.

"From these figures it will be seen that a control area unaffected by the discharge cannot be obtained within hundreds of yards on the leeward side of the electrified area.

"The immediate problem is the provision of a genuine control area, near enough to the charged wire to be under similar conditions to the electrified area as regards soil, climate, and exposure. This is by no means an easy matter, but experiments at present in progress make one hopeful that partial success may be obtained by placing a netting of galvanized iron wire, 10 or 12 ft. high, between the control area and the charged wire. The netting will need to be of comparatively close mesh, but for the purposes of a critical experiment the difficulties in the way of erecting such a netting can readily be overcome. A more serious difficulty is that even with this barrier inserted, preliminary observation suggests that it will still be necessary to stop the discharge whenever a strong wind is blowing from the electrified area towards the control."

Concerning experiments locally conducted in Worcestershire, Mr. J. E. Newman has favoured me with the following particulars, under date 20th January, 1914:—

"The 1913 results (trials with potatoes only) are not yet available, as the crop has not been sold, and is only weighed as it goes away. Neither are Mr. Low's figures ready.

"The most complete experiments are those on wheat (all at Mr. Bomford's, at Bevington)—

		Increase.	
1906 ...	Field A	39 %	(Red Fife)
		29 „	(White Queen)
1907 ...	Field A	29 „	
1908 ...	Field B	24·3 „	
1909 ...	Field C	23 „	
1910 ...	Field C	22 „	
1911 ...	(Drought) Spring-planted wheat, Field A ...	0 „	Yield 16 bus. per acre both areas
1912 ...	Field A	20 „	
1913 ...	No wheat grown.		

"The unelectrified yields have always been from 30 to 36 bushels per acre—the average yields of the whole country—with the exception of 1911.

"The power consumed is 500–750 watts, for an area of 20 acres.

"I am sorry I cannot give the total hours run, as the log-book is at Mr. Bomford's; it averages 6–8 hours per day during the growing period. The discharging wire is No. 24 silicium bronze, spaced 10 yards apart. Tension = 3/4-in. spark to earth, between 1-in. balls."

* *Journal of the Board of Agriculture*, vol. 22, p. 582, 1913.

The current under the electrical treatment is raised to some ten thousand times its normal value. That is not large: it is only 10 milliamperes per square kilometre. That is still a low figure, because the normal value of the current, as I said, is absurdly minute. It is a low figure in the matter of energy, even at 100,000 volts: not more than 4 actual watts to the acre. The process does not consume much energy, for although the potential is high the actual amount coming off the wires is small. A very moderate amount of power will cover a considerable acreage, say 20 acres, even with all the sources of loss; a 2-h.p. oil-engine is found sufficient for a farm.

Another place where these experiments are going on is Mr. Low's farm at Balmakewan in Scotland; and they are also going on to some extent on the Continent. More experiments of this kind are very desirable, and that is one reason why I bring the subject before this audience; experiments require repetition in a great many places, because they are so slow, and it is necessary to have a large number of variations going on concurrently to gain experience. I believe that they would be conducted best not on a large scale, but on a small scale in a greenhouse. But some collaboration with a chemist or botanist, or both if possible, as well as with an electrician, is required. It is an electrical problem to look after the insulation; and also to see that these high tensions are safe. With regard to Mr. Newman senior's greenhouse at Bristol, he has it so arranged that by opening the door the wires automatically earth themselves—one being attached to the door. Otherwise it would be dangerous to go in.

There is a great deal more to be done in this direction, and I bring the whole subject forward as an agendum, something that might be worked up.

Possible Influence on Weather.

I want to say one word more about a much larger scale work than this of agriculture. I say nothing about fume deposition at all, this time; that is another matter, though it is closely allied to the subject. I say nothing about the electrification of fume and dust in factories, but I do want to say something more about the electrical aggregation of drops and a possible effect on weather. I have already said that it is uncertain as to which is cause and which is effect, but if the weather is influenced by natural electrification of the air, then that electrification ought to be taken in hand. If we want rain we should reverse the sign and send up negative electricity; if we want fine weather we should send up positive electricity. The difficulty is to get it high enough up and in sufficient quantity. It must be an expensive experiment; but on the top of a mountain, with kites and balloons, and with proper engineering arrangements for permanently doing whatever is desired in the direction of getting up a sufficiently high tension and discharging an adequate quantity—adopting whatever means is best adapted to that end—something is bound to happen. A thunderstorm might be produced; at any rate that would be an interesting thing to do. I see no reason why experiments should not be made on a sufficiently large scale to see what happens.

I do not know whether members remember a very early novel by Mr. Marion Crawford where he makes his hero devise a peculiarly efficient galvanic battery. He does not care much about considerations of energy: a number of cells in series gave him not only a tremendous potential, but also a tremendous current. He surrounds the hills with wires on little insulators, little things that would not insulate really at all adequately, and he electrifies the whole. He gets all sorts of curious effects. He brings on a thunderstorm certainly, but he brings on many other things, for which I will refer members to the book. "With the Immortals" I think was its title; it is a long time since I read it.

I feel that there are parts of the earth, and parts of the earth belonging to the British Crown, which would be the better for some weather control.

And there is one other suggestion that I want to make, which is perhaps rather an absurd one. I have assumed that we proceed with artificial electrification, on the basis of directly trying to assist, shall we say, the sun in maintaining the positive gradient, for the good of plants or for any other purpose—or else on the basis of interfering with the sun and supplying negative electricity when the sun is supplying too much positive. Is there any other way? Is there any way of artificially interfering with, and deflecting, some of the particles received from the sun? We get, as I hinted, the positively electrified solar particles mostly down in the tropics, the alpha rays; and the negative charged particles go to the Poles. Why? Because the earth is magnetized. Supposing we reversed the magnetism of the earth! Or supposing we interfered with the magnetism of the earth! Then we should get a number of those negatively-charged particles down where they do not go now. Help them down by a large magnet! Surround the earth with a girdle of very thick copper. Not on the equator, because that is too far round, but up nearer the North Pole. Send a very big current round it. It is a matter of arithmetic what current will suffice; but the doubt about the arithmetic is this: What does the earth consist of? If the earth is mainly native iron, and if its temperature, or its temperature over vast regions, is not above the critical point of iron, the permeability of the earth will be very considerable and a million amperes will do something. But if there is no iron in the earth, or if it is above the critical point, then that current would not be sufficient. At any rate we could ascertain its condition by trying to re-magnetize the earth. It seems an absurd thing to put anything like a bar round the earth, but it is a familiar fact that four metal bars—400 I should think—run the whole length of England, all artificially put down. They are called lines of rail. And they stretch all across America. They do not yet go from the Cape to Cairo, but they will be going across Persia to India. People can put down large masses of metal when they have good reason for putting them down.

With that rather absurd suggestion, which perhaps ought not to be taken too seriously, about influencing the cosmic causes of the distribution of our atmospheric electricity (for I think really more seriously of the direct electrical method of more local attack) I will conclude this Kelvin Lecture.

Dr. R. T. Glazebrook: I presume that it is because I had the honour to deliver the last of these series of Kelvin Lectures previous to that of Sir Oliver Lodge that I have been invited this evening to express to him the Dr. Glazebrook.

Glaze-ok thanks of this meeting for the lecture which he has given to us, and to ask that he will most kindly fulfil that promise which he has already made that the lecture shall be printed in the *Journal*. I am afraid that the President gave to our lecturer this evening an impossible task if he really suggested to him that he was to deliver the Kelvin Lecture without referring to the work of Lord Kelvin. I do not think his letter exactly took that form. But no doubt he wished to give Sir Oliver a free hand in the subject that he selected for the lecture, and I am sure we are all very glad that that was done. The Kelvin Lectures of the past have dealt mainly with some specific part of Lord Kelvin's work. Obviously it is not possible that that should always be continued, and the connection which Sir Oliver has shown between the commencement of the work of the measurement of atmospheric electricity and Lord Kelvin is surely sufficient to justify him in talking to us to-night on this most interesting and important subject of atmospheric electricity. He has told us that he was not giving us a résumé of past achievements but a programme for future work. We have to thank our President for advance along many paths of progress, and among those I should like particularly to refer to the inauguration of the Research Committee of the Institution. May I suggest that this lecture which we have had from Sir Oliver Lodge may perhaps be the first of those reports on the state of science about which we have heard something at the Council this afternoon, and may lead to future research work of real national importance on the subject that has been brought before us. We are always glad to see Sir Oliver Lodge here; we are always pleased to listen to him, and we recognize on all occasions the inspiration of the words that come from him. I will only ask you, therefore, to offer a very hearty and cordial vote of thanks to him, and to request him to allow this lecture to be printed in our *Journal* in the usual way.

Thomp- Dr. Silvanus P. Thompson: I am delighted to second the motion which has been proposed by Dr. Glazebrook, to convey our thanks in the heartiest way to Sir Oliver Lodge for the lecture which he has delivered to us. We have been led into a branch of electrical studies with which probably comparatively few of us are familiar. Indeed, it sounds almost like the founding of a new science—that of electro-agriculture—to which we have been treated to-night. What will be thought a hundred years hence by those who turn up the *Journal of the Institution of Electrical Engineers* for the year 1914 when they discover how little we knew about electro-agriculture, which by then will have transformed the face of the earth! People have been at it for a long time. I have in my possession a delightful old engraving more than a hundred years old which represents an electrical greenhouse provided with wires and spikes for electrifying the plants in pots, and somewhere in the background someone is turning the axle that drives a pair of curious old electrifying machines, and the plants are supposed to be enjoying it. We have heard of the aurora borealis, but I think not even Sir Oliver Lodge has alluded to the very remarkable fact that in the short summer of the Arctic regions they can gather a larger number of crops than we can in our lower latitudes, or than can be gathered even in still lower latitudes nearer the equator. Why is it that in the Arctic regions in that short summer the plants grow so exceedingly quickly? Why is it so if indeed the aurora borealis is not accountable for the stimulating effect? Now in those old attempts Dr Thompson. that were made a hundred years ago to electrify plants with the old electrifying machines they failed, and failed for very obvious reasons. They had never thought of those things that have been brought so excellently before our attention to-night, the hints which Nature and modern electrical art have given towards understanding natural processes. Did it ever occur to any of us before now what was the use of points on the leaves of plants? Well, we know. There is the picture that was shown to us. We do not want to be sending discharges from spikes to the plants, but we should let the plants use their own spikes in their own natural way, and simply help them by a larger potential gradient. What did we know about potential gradients 50 years ago? Practically all that we knew was what we learnt from Lord Kelvin's measurements. So once more the old truth is justified that if we examine patiently and without hope of reward into the facts of Nature and correlate them and make them scientifically available, they justify themselves in the long run. And what seemed to be one of the most unprofitable researches, the mere measurement of difference of potential between one height in the atmosphere and another, turns out to be the key to an important industrial application years after. Who would have thought in experimenting with pretty vacuum tubes and an induction coil, and sending sparks through, and finding—by accident probably—that it was rather easier in some cases to send a spark through the tube from one end to the other than it was to send a spark from the other end to the one, that in that incidental fact there was the beginning of something which might be improved and magnified, something which, with careful work in the Birmingham Laboratory, might be developed into an electric valve; and with the electric valve came the possibility of piling up the potential and obtaining these charges at high voltage with a comparatively simple apparatus! We have been told what is the voltage that is employed in these agricultural experiments, but are there not experiments going on on almost as large a scale even now which might be used for agricultural purposes? There are such things as transmission lines in other parts of the country than this, where people are working at 60,000 volts, 120,000 volts, and 150,000 volts. Is the vegetation improved underneath those? It ought to be under certain circumstances. [Sir Oliver Lodge: It is alternating current.] What are the circumstances? We are told that it is alternating current, but it is not all alternating current. Mr. Highfield will at once challenge that. If we have a non-alternating-current line, is the vegetation underneath that line improved? Is the vegetation improved if the electrification of the line is positive? We should like to know. Moreover, there are other ways in which the ionization of the air can be improved, when it occurs without being intentionally brought about. We have had a most suggestive lecture. We have been stimulated by the high potential—not too high over our heads for us all to enjoy it—of the intellectual atmosphere. Doubtless we may look forward to many and great results from the delivery of this lecture. There are many of us here who are keenly interested in some little part perhaps of the subject. Perhaps there are some here who take a direct interest in agriculture. Surely they

will give their help to give publicity to this great fact that is already established—that electric discharge under proper conditions, under scientific control, with an understanding of the natural processes that are going on, does improve the output of the crop. It is only a question of learning a little more as the seasons roll by, and of finding men willing to make the venture of spending capital upon it. There is nothing needed more than that to put the discovery into effective operation. My mind goes back some 25 years, possibly more, to the time when electric lighting was nearly new, when the late Sir William Siemens—the first President of this Institution—produced things from his experimental farm, if I might call it so, from his estate in the South of England, where he was stimulating the growth of maize and wheat, and other crops, not directly by electric discharges, but by giving them an extra dose of electric light at night, prolonging the daylight for them and increasing their growth. Unhappily it was not found to pay. But now we have a new departure in the novel science of electro-agriculture, and having had it so admirably expounded to us in a way that we have all been able to follow, surely we may look confidently for great results. I venture to think there will be direct results from Sir Oliver Lodge's address to us. We recognize that the memory of Lord Kelvin has been well and worthily honoured by his latest exponent.

The Resolution was then carried by acclamation.

Sir Oliver Lodge.

Sir OLIVER LODGE: I thank members very much for their reception of me. It is a great pleasure to meet so many electrical engineers and to talk to such an audience. I should have liked a little more time, but I took up quite enough. I wish also to thank the two Past Presidents for their eloquent speeches. I just wanted to say one word suggested by the remarks of Dr. Silvanus Thompson. We have found hedges underneath a high-tension wire that was leading to another part of the farm grow very decidedly. It happened quite unintentionally. They sent up shoots decidedly higher than another part of the same hedge. I had some other lantern slides showing those effects but I thought it better not to go through them all.

I hear that some attempts have been made with high-tension alternating current—utilizing a kind of Tesla effect. I have not heard that they have been successful, and I should not anticipate that they would be. At any rate I think that a charge of one sign will be more efficient. The natural high-tension effect spoken of by Dr. Thompson has, perhaps, been observed. The President tells me it has been observed in some cases: that under a wireless area, the area of a wireless Marconi installation, the grass is found to grow better than it did before. I expect that, when looked for, these effects will often be found. I echo the wish that has been expressed—and that is one reason why I brought this forward—that we shall get more investigators into this field. The field is perfectly open to anybody. The experiments are interesting, though rather slow, but with all the skill here present they might be put into operation, and I hope that 10 years hence we shall get a very large number of positive results.

(*Communicated*): The American Consul in Birmingham, Mr. Halstead, has kindly sent me an extract of the *American Expositor* of recent (but to me unknown) date, which contains an account by Dr. H. G. Dorsey of some initial small-scale experiments conducted in America. And, inasmuch as enquiries are often addressed to me about the relative advantages of other methods of treatment, especially as to the advantage of earth currents sent among the roots of plants, I think that a quotation from this paper may be permissible and interesting, although the experiments that it records are of a very initial and tentative character. But the whole subject is essentially new, and many things must be tried. The method advocated by me was not employed by these experimenters, but a Tesla alternating discharge was one of the things tried and apparently gave good results. It is noticeable that electricity applied directly or indirectly to the soil or roots did no good at all; it was only good when applied to the aerial portions of the plant.

"In order to advance the work of intensive culture which might be applied in the Boys' Gardens, President John H. Patterson, of the National Cash Register Company, suggested among other things that the effects of electricity and artificial illumination be tried. The following tests were made possible at Moraine Farm through the generosity of its owner, Mr. E. A. Deeds, vice-president of the company. Moraine Farm is situated about four miles south of Dayton, Ohio, in the fertile valley of the Miami River, and is equipped with almost every form of modern electrical apparatus which may be applied to farm and residence use.

"During January and February of 1913, preliminary experiments were carried out by Mr. F. O. Clements, the company's chemist, and the writer, in the greenhouse of Moraine Farm. Seven plots were prepared about three feet square each, and were partitioned from each other by thin wood partitions in such a manner that each received full sun and sky light. In order that the soil might be uniform in the different plots, it was thoroughly mixed and sifted together and then placed in the different plots to a uniform depth of about six inches.

"Plots 6 and 7 were subdivided into four individual boxes each one foot square, which were separately insulated with porcelain insulators and supplied with carbon electrodes on the inside at opposite ends of each box. To these carbon electrodes was applied both alternating and continuous current. In Plot No. 7, 60-cycle alternating current of 110 and 220 volts was applied to one box and 1·5 volts from a dry cell was applied to another. The other two boxes were similarly excited, but only after germination. The currents in the eight boxes varied from 0·0003 ampere to 0·07 ampere, depending on whether the boxes were freshly sprinkled or nearly dried out. There was no apparent difference between the effects of alternating and continuous current. All 8 boxes maintained a temperature a few degrees higher than the other plots, due to the heating effects of the current in the soil. The results were uniformly poor, germination being retarded and growth being stunted. Later experiments were tried in cigar-boxes with voltages from 3 to 8 volts supplied by dry cells, the currents varying from 0·0007 to 0·05 ampere. These tests also showed evil results instead of good and from our standpoint earth currents proved a complete failure, and Plots 6 and 7 were abandoned.

"Plot 1 was excited by high-frequency currents from a

small Tesla coil. A small transformer raised 110 volts 60-cycle alternating current to 5,000 volts, and charged a condenser of tin-foil and glass plates which discharged through the primary of the Tesla coil and a spark-gap. A network of No. 30 B. & S. gauge wire was stretched about 15 in. above this plot and connected to one terminal of the Tesla coil, the other terminal being connected to a wire screen which was buried in the bottom of the plot. The transformer and boiler took about 130 watts and were operated for one hour each morning and evening. The potential difference between the soil and overhead wires was about 10,000 volts, and the frequency may be about 200,000 periods per second.

"Plot No. 2 was illuminated by a 100-watt tungsten lamp with ruby bulb 3 hours per day, beginning at sundown. Plot No. 3 was illuminated by a Cooper-Hewitt mercury-vapour lamp 3 hours per day, beginning at sundown. Plot No. 4 received no artificial stimulation and was used as a control plot, so that comparisons might be made between the plots receiving excitation and one receiving none. Plot No. 5 had a wire network buried in the bottom which was connected to the negative terminal of a 110-volt continuous-current circuit. The positive terminal was connected to a small sprinkling can which had a carbon electrode in the middle insulated from the can itself. A small insulating stand was provided on which this sprinkling can was placed. The can being filled with water was then electrolized for about 3 minutes. During this time the temperature of the water would rise from about 70° Fahr. to 90° and become considerably gaseous by the evolution of oxygen and hydrogen from the water. While still bubbling, the negative terminal to the can was opened and the plot sprinkled, the idea being that current might flow from the can through the streams of water to the soil.

RESULTS AFTER 3 WEEKS' ELECTRIC STIMULATION.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
			RADISHES.		
Ten plants selected at random:	Tesla.	Ruby	Violet	Control	Elec. Sprinkling
Total plant weight (grammes)	265·7	137·8	109·5	180·0	78·5
Edible portion (grammes)	139·5	57·4	40·9	79·4	31·0
Edible portion (per cent)	51·15	41·65	37·34	44·11	39·49
Tops and leaves (grammes)	120·5	75·7	65·9	95·0	41·5
Tops and leaves (per cent)	45·35	54·92	60·18	52·77	55·66
Roots (grammes) ...	9·3	4·7	3·2	5·6	6·0
Roots (per cent) ...	3·50	3·43	2·48	3·12	4·85
			LETTUCE.		
Ten plants selected at random:—					
Total plant weight (grammes)	67·0	52·6	56·5	46·1	31·3
Edible portion (grammes)	60·7	47·3	50·2	41·8	28·2
Edible portion (per cent)	90·59	89·92	88·85	90·67	92·1
Roots (grammes) ..	6·3	5·3	6·3	4·3	3·1
Roots (per cent) .	9·41	10·08	11·15	9·33	7·99

"All of the plots were planted with radish and lettuce seed, samples of which had previously been tested for germination to make sure they were good seeds. No germination tests were available in the plots because mice ate several of the seeds at the beginning of the test, so that the results show only the effects after germination. All plots received exactly the same treatment other than the stimulation. No stimulation was attempted on Plots 1 to 5 until after germination. The seeds were planted on 16th January, and on 29th January stimulation was begun on Plots 1, 2, 3, and 5. About 3 weeks later 10 plants each of radish and lettuce were selected at random from the 5 plots and weighed as shown in the table appended.

"From this table it will be seen that the high-frequency currents caused a greater increase in yield than any of the other methods of stimulation. Ruby light ranged second for radishes, but violet light ranged second for lettuce. The electric sprinkling system was worse than no stimulation at all. Comparing the high-frequency plot with the control plot we find that the edible portion is 75 per cent greater with the lettuce.

"We next attempted to repeat these experiments using tomatoes and cucumbers, but were prevented from getting any results because of interruption by the Dayton flood.

"The results obtained from the high-frequency tests were sufficiently encouraging to warrant us in starting something on a larger scale. A 2-acre plot of good soil was selected in a flat field to be used as a house garden, and this was arranged to be sprinkled by an overhead sprinkling system. Pipes were suspended from a catenary suspension system 14 ft. above ground, the pipes running east and west 200 ft. and spaced every 50 ft. north and south for a distance of 400 ft. In the north-east corner of this garden seven wires of No. 12 B. & S. hard-drawn copper were stretched north and south 200 ft., the wires being 9 ft. above ground and 15 ft. apart. The ends of the wires were attached to insulators on top of 4-in. gas-pipes set in concrete, and at the middle they were supported by suspension insulators from one of the lines of sprinkling pipe. Both types of insulators were built for 60,000-volt power circuits. This system was sufficiently high so that the soil could be ploughed with horses. It should be noted that the high-frequency system was independent of the sprinkling system. Occasionally the two were run at the same time, but not often.

"At the eastern edge of this plot was built a small transformer house, in which a 7·5-k.v.a. transformer stepped up 220 volts 60 cycles to 11,000 volts. A choke coil was placed in series with the primary. The secondary was connected to a spark-gap, and shunted across this was the condenser in series with the primary of the Tesla coil. The primary of the Tesla coil was made of 8 turns of No. 0000 wire, and the secondary consisted of 75 turns of No. 14 B. & S. gauge on a wooden drum 15 in. in diameter and 18 in. high. The primary and secondary were both immersed in a 50-gallon stoneware jar full of transformer oil. The bottom end of the secondary was connected to the pipes of the sprinkling system, which furnished an earth connection, and the upper end of the secondary was led through a 60,000-volt bushing from the transformer house to the middle of the antennæ, which were connected together by a wire running east and west. The spark-gap was formed of two rectangular boxes of thick copper, with two faces parallel and 1/4 in. apart. The boxes were hollow and filled with water, and gave excellent service as a stationary spark-gap.

"Considerable difficulty was experienced in getting the system to work properly. Condenser plates were continually breaking down until the condenser was built of old photographic plates 8 by 10 in., two glass plates, and

then a sheet of tin-foil. Two boxes containing about 300 glass plates and each filled with transformer oil gave a good condenser of about 1/10 microfarad capacity which did not break down, and it was not even necessary to remove the coating from the plates. Trouble was also experienced in finding a suitable container for the Tesla coil immersed in oil until the stoneware jar was thought of. Taking into account the various delays, it was the latter part of July before the system could be considered in perfect working order. At that time it was giving the full 50,000 volts, as measured by the needle spark-gap between the antennæ and earth. For several weeks previous to that time, voltages of from 10,000 to 20,000 could be maintained. The garden was electrified daily from 6.30 to 9.30 a.m. and from 1.30 to 3.30 p.m.

"The frequency of the oscillatory currents was estimated to be about 30,000 cycles per second, and at 50,000 volts sufficient energy was radiated from the wires so that birds in attempting to light on the wires received such a shock that they fell to the ground partially stunned. None, however, were actually killed by the current.

"Because of the lateness in getting the system into working order, qualitative rather than quantitative data only are available. However, it was very apparent that almost all the vegetables grown under the wires were better than those not electrified. These included radishes, lettuce, beets, cabbage, cucumbers, turnips, musk melons, water melons, tomatoes, and parsnips. Little or no difference could be observed in beans and peas. With the exception of these, however, the gardener in charge picked almost all the others at least two weeks earlier under the wires than under the unelectrified portions. All these different vegetables were planted in rows running east and west so that one-half of the rows were electrified and the other half not. Actual weights were obtained only in the case of tobacco. One end of a row was cut under the wires and the plants averaged 1,687 grammes per plant. One week later the other end of the row was cut and the plants averaged 1,632 grammes per plant, so that there was a gain of 55 grammes per plant, or an increase of 3·35 per cent in the crop electrified. Since the largest part of the tobacco growth occurs during the last two weeks, it is estimated that the actual increase in weight, if both ends of the row had been cut at the same time, would have been about 20 per cent."

APPENDIX.

In order to convey supplementary information to those interested in the subject of electrification of crops, and in order to answer many questions and make the lecture more complete, I hope it is permissible here to reproduce the substance of a pamphlet which I wrote and privately printed in or about 1908, and which is not otherwise accessible.

Electricity in Agriculture.

Some thirty years ago a Swedish professor named Lemström sought to elucidate the aurora borealis by trying to imitate its appearance by electrical experiments. For this purpose he produced high-tension discharges of various kinds, and sent them through vacuum tubes until he got an appearance very like those of the northern lights. Some of these experiments he conducted in his greenhouse, and he noticed incidentally that the plants seemed to thrive under the treatment, and that the electrification thus produced in their neighbourhood appeared to do them good. He also noticed, as remarkable, the flourishing development of plants in Arctic regions, where the sunlight was very weak; and he attributed part of this growth to the influence of electric discharges.

He says that when the plants in the North of Norway, Spitzbergen, and Finnish Lapland, have resisted the frequently destructive night frosts they show a degree of development which greatly surpasses that of plants in more southern regions, where the climatic conditions are more advantageous. This rich development appears principally in the fresh and clear colours of the flowers, in their strong perfume, in the rapid development of the leaves on the trees, and their scent, but particularly in the rich harvest which different seeds—such as rye, oats, and barley—will produce, when, as before stated, they are not destroyed by the frosts. From a bushel of rye sown they will often produce 40 bushels, and from barley 20 bushels, and so forth. It is the same with grass. These results are attained although the people cultivate their soil very imperfectly, using only ploughs and harrows of wood.

He pursued the matter by careful observation, taking test plants in pairs or groups, electrifying one group—that is to say, discharging some electricity into the air above them—and keeping a similar group away from the electricity, in order to be able to compare them. Then he photographed the two groups side by side, and found in nearly all cases a marked improvement as the result of the electrical treatment. He concluded that the needle-like shape of the leaves in fir-trees, and the beard on the ears of most cereals, have the discharge of electricity as their function, and finds that they do act in this way.

This observation and these experiments of Professor Lemström were not, indeed, the beginning of the application of electricity to plant growth, because pioneer attempts had been made long before, as will be mentioned directly, but it was the beginning of a thorough and scientific treatment of the problem. Attempts of a different kind had also been made. Plates had been sunk in the ground, and a current passed between them among the roots of plants; but whatever effect is thus caused is of a totally different kind to that excited by high-tension electricity supplied to the air above them. Both in a manner are natural processes. There are natural earth currents, and these must flow among the roots of plants, though whether they produce an appreciable effect may be doubted.

There is a natural atmospheric electrification, and this must be playing an important part in many phenomena. Atmospheric electrification is responsible for the formation of rain and hail. During fine weather the electricity in the air is usually of one sign: mainly positive. When wet weather sets in, the electricity in the air usually changes sign, becoming negative. The whole subject is a large one; a great deal is known about it, and vastly more remains to be known; but meanwhile it can hardly be doubted that the electrification of the air has some effect on growing plants. For it is found that, under the influence of sunshine, electrified plants can give off electricity from the leaves; and the fact that the air is naturally electrified relatively to the soil causes all plants to be

electrified too, so that in all probability they are in a constant state of slow electrical discharge, which becomes more rapid when the sun is up. In what way this discharge of electricity from their growing tips, and hair, and surface generally, really acts, must be studied and reported on by physiological botanists; but it is natural to suppose that it cannot be without influence, and reasonable to think that the influence may be beneficial—a hypothesis which direct experiment confirms.

Possibly, in some sunny countries the effect is excessive, and might, with advantage, be moderated; but in this climate it turns out that artificial supply of electricity does increase the rapidity and assist the amount of growth. At any rate, the experiments of Lemström, which were repeated and extended by others, clearly pointed in that direction. So when, after some preliminary experiments at Bitton, Mr. J. E. Newman, of Gloucester, acting in conjunction with Mr. R. Bomford, of Salford Priors, determined to try the phenomena on a really large scale, and came to me to see if I could help them electrically, and enable them to maintain a continuous high-tension discharge for hours together each day over ten or eleven acres by means of power furnished by an oil-engine and dynamo, I very willingly assented, and set my son, Mr. Lionel Lodge, upon the job.

The method is to stretch over the field to be treated a number of wires on poles, something like low telegraph wires, but high enough for loaded waggons and all the usual farming operations to go on underneath the wires without let or hindrance. The wires are quite thin, and are supported by a few posts in long parallel spans, about 30 ft. apart. They are supported on the posts by elaborate high-tension insulators, and they extend over all the acreage under experiment, a control plot of similar land under similar conditions being, of course, left without any wires.

The system of conductors is then connected at one post with a generator supplying positive electricity at a potential of something like 100,000 volts, and with sufficient power to maintain a constant supply of electricity at this kind of potential.

Leakage immediately begins, and the charge fizzes off from the wires with a sound which is sometimes audible, and with a glow just visible in the dark. Anyone walking about below the wires can sometimes feel the effect on the hair of the head, as of a cobweb on the face. They are then feeling the stimulating action of the electrification.

The electrification is maintained for some hours each day, but is shut off at night: it is probably only necessary to supply it during the early morning hours in summer-time, and in spring-time or in cold cloudy weather for the whole day. In bright sunshine it seems unnecessary or even harmful. But at what stages of the growth of a plant the stimulus is most effective has still to be made out. Probably the earlier the better; and since in the case of wheat, both the ear and the straw is valuable, the electrification should be applied for a time each day during the whole period of growth until stooling begins.

The power required to generate the electricity is very small, for although the potential is high the quantity is insignificant, and the energy is accordingly comparatively trivial. It is known that even when natural atmospheric electricity has accumulated intensely, and has become a thunderstorm, the quantity even then is quite small, though the potential or tension is so enormous that the flashes are of astonishing violence and power while they last.

The electricity can be generated in more than one way. It can be generated by the revolving glass plates of a static influence machine, usually known in this country as a Wimshurst machine; or it can be generated by transforming up to high tension, and rectifying to one direction, the current of the revolving magnetic generator called a dynamo. The first is in many respects the simplest, and was used in the early and small-scale experiments, but it can hardly be regarded as an engineering method adapted to continuous or rough use.

The latter is the one which in the trials now to be described we have adopted.

The power is generated by a two-horse oil-engine driving a small dynamo in an outhouse of the farm. Thence the current is taken by ordinary overhead wires to the field, where they enter a suitable weather-tight hut, which contains the transforming and rectifying apparatus. The only moving part here is the "break," and if the original dynamo had been an alternator, even this might be dispensed with. The transformer is a large induction coil, specially made to stand continuous use, and its current is then rectified by means of vacuum valves in accordance with a patented device of my own.

The negative electricity is conveyed direct to earth, except when retardation is desired, or during drought; while high-tension electricity, all of positive sign, is led by a specially insulated conductor out of the shed to the nearest post of the overhead insulated wires, which are thereby maintained at continuous high positive potential.

The Results and Further Details.

The following is a very brief summary of returns and information supplied to me by Mr. Newman and Mr. Bomford, showing the results from the electrified as compared with the control unelectrified plots.

Summarized Results of the 1906 Experiments.

BUSHELS OF WHEAT PER ACRE.

(*Estimated corresponding increase in straw not measured.*)

	From the electrified plot	From the unelectrified plot	Increase
Canadian (Red Fife) ...	$35\frac{1}{2}$	$25\frac{1}{2}$	40%
English (White Queen)...	40	31	30 ,,

Moreover, the electrified wheat sold at prices some $7\frac{1}{2}$ per cent higher, several millers in baking tests finding that it produced a better baking flour.

The increase appears to be mainly due to better stooling. No marked difference was observable in the development of ears.

Summarized Results of the 1907 Experiments on Wheat.

RED FIFE, SPRING SOWN.

Bushels per Acre (*Head Wheat*).

Electrified	Unelectrified	Increase
41·4	32	29 per cent

Electrified wheat brighter, and a better sample.

Increase again partly due to stooling, but this time there was better filling out of ears.

These results are for wheat alone, but a good many other crops were tried at the same time, and they appear in the more detailed statement below.

HOURS PLANT RUNNING.

1906.

16th March to 10th July, inclusive, 621¾ hours on 90 days. Average electrical pressure corresponded to a ¾-in. spark.

Current shut off after ears in bloom.

1907.

28th March to 27th July, 1,014 hours on 115 days. Average pressure corresponded to a ½-in spark.

Current kept on till harvest.

FURTHER INFORMATION, PARTLY FROM MR. NEWMAN.

In 1906, owing to the late delivery of some of the apparatus, the work had to be carried on with a somewhat improvised generating station at the commencement on 16th March. By the end of May, however, the installation was completed, and worked fairly continuously during the rest of the season, the current being supplied intermittently until 10th July, by which date the wheat had been in ear about a fortnight.

The complete arrangements for generation of the high-tension currents are as follows :—

Direct current, about 3 amperes, at 220 volts, is generated by a dynamo, driven by an oil-engine of about 2 h.p. The current passes from the dynamo through the primary of a large induction coil, with a make and break contact interposed in the circuit. From the secondary of the coil the high-tension current passes through the rectifiers, and then by one pole to the system of overhead wires, the other pole being earthed.

The overhead system of wires covered about 19½ acres of ground. The wires were mounted on insulators placed upon larch poles, some 15 ft. high, which were placed in rows, the rows being separated by a distance of 102 yards, and the poles in a row being 71 yards apart. Stout telegraph wire carried the current down each row, while thin galvanized iron wires, placed some 12 yards apart, were stretched between the rows, and acted as the discharge wires. In this way 22 poles were sufficient to support the wire over the 19 acres.

Roughly, only one pole per acre is required ; so the inconvenience is practically nil.

The height at which the wires are taken allows a loaded wagon to go beneath.

Owing to the flexible suspension, risk of breakage to the wires is very small. (During the two years the wires have been up at Bevington, apart from a few wires broken at harvest-time by catching in top of extra high wagon load, only one wire has fallen.)

The acreage was spread over two different fields : in one field some 11 acres of wheat were under treatment, in the other 6½ acres of barley, and a half-acre plot planted with potatoes, mangolds, etc.

The wheat field was of 18½ acres extent, the remaining 7 acres were sown with English (White Queen) wheat, 1½ acres, and Canadian (Red Fife) on 5½ acres. In the electrified part Canadian wheat occupied 2½ acres, English wheat 9 acres.

The results on the barley field, including the small plot, had to be neglected owing to the great local variations produced by the very irregular manuring the field had previously undergone. The wheat field, however, as far as one could judge, had been very uniformly treated previously.

In the wheat difference was noticeable at an early stage, the young blades on the electrified part being, in the opinion of many observers, of a darker green.

The crop was judged as considerably heavier by several practical observers, and the straw was, on an average, from 4 in. to 8 in. higher. Both experimental and control plots came into ear at about the same time, but the Canadian wheat under treatment was ready for cutting some three or four days before the control area.

The crops were gathered separately from the electrified and unelectrified plots, and the resultant yields were as follows :—

BUSHELS PER ACRE.

(*Estimated corresponding increase in straw not measured.*)

	Electrified	Non-electrified	Increase
Canadian (Red Fife) ...	35½	25½	39 per cent
English (White Queen)	40	31	29 ,,

Moreover, the electrified wheat sold at prices some 7½ per cent higher, several millers in baking tests finding that it produced a better baking flour.

No theoretical conclusions can be drawn from this fact, owing to the uncertainty existing as to what factors determine the strength of wheat, but it is interesting to note that greater strength is usually accompanied by increase in percentage of total nitrogen.

Mr. J. Kirkland, of the National School of Bakery, Borough Polytechnic, found the evidence from baking tests supported by the average of dry glutens from all his tests thus :—

In the electrified	11·15 per cent
In the unelectrified ...	10·35 ,,

The somewhat poor yield of wheat obtained from the unelectrified portion of the field is probably explained by a deficiency in lime, which has now been rectified. Further, the wheat was spring sown, and Red Fife, under this condition, does not usually yield good crops. The experiments are being repeated upon wheat during the present season, and strawberries are also under treatment once more.

In 1907, wheat was grown again in the 1906 wheat field. Current cut off from most of the barley field, which was down to clover and rye grass. 8¼ acres in an adjoining field planted with strawberries (Stirling Castle) in March, approximately 2¾ acres having a wire network erected over them. Mangolds were planted between the strawberry rows.

The wheat field was during the early spring given a dressing of lime 10 cwt. to acre, 4 cwt. to acre bone meal drilled in, the unelectrified part given 1½ cwt. sulphate of ammonia, and the electrified part ¾ cwt. Barley had been grown on the strawberry field in 1906, and this was

given 10 tons to acre of farmyard manure, which was ploughed in.

Result of Crops, 1907.

WHEAT.

(*Variety, Red Fife, Spring Sown.*)

7½ acres unelectrified gave	239 bus., 38 lb.	Head Wheat.	15 bus., 1 lb.	Tail
11 ,, electrified	455 bus., 50 lb.	,,	17 bus. 27 lb.	,,

Or, summarizing as before—

BUSHELS PER ACRE (HEAD WHEAT).

Electrified	Unelectrified	Increase
41·4	32	29 per cent

Electrified wheat brighter and a better sample. Increase due to better stooling and also better filling out of ears.

STRAWBERRIES.

During the first year, the crop was necessarily very small and was picked chiefly to see if any increase had been obtained. The result showed a 35 per cent increase. Earlier ripening was also observed.

Analysis of Samples of the Fruit taken from Bulk.

Mangolds.—It was found impossible to weigh either the whole or a part of this crop. Estimated increase (from number of cartloads removed), 25 per cent. Analysis showed an increase in the sugar where electrified, but the results varied considerably.

Small plots of raspberry canes showed a marked improvement in growth.

Small plots of tomatoes also showed large increase in the crop.

(A curious point about the raspberries was that the foliage and fruit on the old canes showed no difference, but that the new growth, particularly after the old wood was cut back, showed an enormous difference in favour of the electrified. Manurial treatment exactly similar.)

Those interested in the experiments are much indebted to the enthusiastic co-operation of Mr. Bomford, of Bevington Hall, Salford Priors, near Evesham. It may be interesting to note that it was at a farm belonging to Mr. Bomford's father that the first steam ploughing in England was done.

Professor Lemström is undoubtedly the pioneer in this sort of work; though circumstances connected with the natural electrification of the atmosphere, and with the discharge of electricity from various surfaces, have been pertinaciously examined by Professors Elster and Geitel.

On the History of the Subject.

Professor Lemström published his results with full details and illustrations, both of the apparatus used and of the appearance of some of the resulting crops, in a small book called *Electricity in Agriculture and Horticulture*, published in English by the Electrician Company in 1904, and it is well worth referring to.

He quotes earlier attempts—one as far back as the year 1746—and describes his own early experiments in the University of Helsingfors, conducted in cardboard compartments in front of a south window, in May and June, 1885.

His only mode of electrification, however, was the old influence machine based on the type of Holtz and Wimshurst, though on account of their inconveniences during prolonged use, he devised a cylindrical type, which he found on the whole more trustworthy; and with it he obtained striking success; for instance, 37 per cent increase in the yield of strawberries.

No doubt most of the difficulties connected with experiments in this subject have been due to the difficulty of supplying the electricity in a continuous and convenient manner. The use of the rectifying valves was expected to get over all these difficulties, but the necessary experience cannot be obtained without large-scale continuous running for a good many hours each day.

In 1907 a paper was read by Mr. J. H. Priestley, B.Sc., before the Bristol Naturalists' Society, and is published in their *Proceedings*, Fourth Series, Vol. I, Part III, 1907; and from this paper the following account is taken:—

One of the earliest modes of supplying electricity to plants, etc., was that of the Abbé Berthelon in 1783. He raised a head of metallic points in the air, in the manner of a lightning conductor, and made it terminate in a series of discharge points just over the plants. He states that the use of this apparatus was invariably accompanied by an improvement in the appearance of the vegetation and by an increase in the fertility of the plants.

An opposite or control experiment was made by Grandeau in 1879, when he protected a plant from atmospheric electricity by means of a wire cage, and showed that its development was greatly retarded.

Other experiments have done the same thing and made careful measurements of the results, which are all in the same direction.

A summary of other workers in these directions, as well as of the less satisfactory methods of supplying electricity in the soil, is also contained in Mr. Priestley's paper.

The work of Professor Berthelot in France, at the Station for Agricultural Chemistry established at Mendon, must be specially noted. He tried the effect of a silent discharge, and particularly of atmospheric electricity upon plants.

He compared the growth at the top of a 28-metre tower with that of plants growing at the foot, and considered that greater growth at the higher level was largely due to the potential gradient in the atmosphere.

Berthelot considers that the clue to advantage of the electric discharge is to be found in an entrance of atmospheric nitrogen into the plant metabolism, but suggests that this is due not only to the formation of oxide of nitrogen, but also to the combination of gaseous nitrogen with carbohydrates within the plant.

Dr. Cook, of Bristol, likewise obtained an increase in the rate of growth by the use of an overhead discharge on a small scale.

Experiments at Bitton in 1904.

During the winter of 1904 Mr. J. E. Newman installed a small trial apparatus, consisting of a small influence machine of the Wimshurst type and overhead discharge wires, at the Golden Valley Nurseries at Bitton, near Bristol. The

wires ran about sixteen inches above the tops of the plants, or above the rows of tomatoes in the glasshouses, and short pieces of fine wire, with the free ends pointing downwards, acted as discharge points.

From 7th March to 26th July the machine was running during 108 days for a period of 9·3 hours daily, principally at night.

In all cases control plots were provided, which, as far as practicable, were under identical conditions.

The crops from the electrified and control plots were gathered and estimated separately, usually by weighing. The result was as follows :—

Cucumbers, 17 per cent increase.
Strawberries (five-year plants), 36 per cent increase.
Strawberries (one-year plants), 80 per cent increase, and more runners produced.
Broad beans, 15 per cent decrease, but ready for picking five days earlier.
Cabbages (spring), ready for picking ten days earlier.
Celery, 2 per cent increase.
Tomatoes, no difference.

A somewhat similar installation was also working in Mr. G. R. Newman's vegetable garden near Gloucester. Here a somewhat higher voltage was given by the influence machine, and the discharging points were kept five feet above the ground. In this case—

Beet showed 33 per cent increase.
Carrots showed 50 per cent increase.

The amount of sugar in the beets was determined as follows :—

The electrified yielded 8·8 per cent total sugar.
The unelectrified yielded 7·7 per cent total sugar.

The results of some small trials with wheat, also made at Gloucester, were very favourable, so Mr. Newman decided to try the effect of the overhead discharge system on wheat and barley on a larger scale.

Thanks to the interest taken in the work by Mr. R. Bomford, of Bevington Hall, near Evesham, Mr. Newman was enabled to use some forty acres of this estate for experimental work in 1906, and experiments commenced on this ground in the spring of that year, and are still being continued.

Some twenty acres of this ground were beneath the discharge field, and, as it was necessary for practical purposes to have the discharge wires at a considerable height, the very high-tension current required was obtained by means of an induction coil and valve rectifiers upon the system devised and patented by Sir Oliver Lodge, who very kindly lent the necessary apparatus.

It was very largely owing to the generosity of Sir Oliver Lodge, and the advice and help of Mr. Lionel Lodge, that Mr. Newman was able successfully to complete the necessary installation and to carry out the experiments.

Since this date Mr. G. R. Newman has established a large installation at his nurseries at Bitton, near Bristol.

Inquiries may be addressed to Mr. J. E. Newman, General Manager of The Agricultural Electric Discharge Company, at 85 Park End-road, Gloucester.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF THE 12TH FEBRUARY, 1914.

Proceedings of the 562nd Ordinary Meeting of the Institution of Electrical Engineers, held on Thursday, 12th February, 1914—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 22nd January, 1914, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and it was ordered to be suspended in the Hall.

Donations to the *Library* were announced as having been received from The Association of Mining Electrical Engineers, W. K. L. Dickson, The Institute of Chemistry, M. W. Jenkinson, Dr. A. E. Kennelly, The Manchester Steam Users' Association, Messrs. Ridsdale & Co., Messrs. E. & F. N. Spon, Ltd., A. J. Stubbs, Dr. S. P. Thompson, F.R.S., and the United States Department of Commerce; and to the *Museum* from E. S. Shoults, to whom the thanks of the meeting were duly accorded.

A paper by Mr. Roger T. Smith, Member, entitled "Some Railway Conditions Governing Electrification" (see page 293), was read and discussed, and the meeting adjourned at 10 p.m.

DISCUSSION ON

"ELECTRICITY SUPPLY OF LARGE CITIES."*

NEWCASTLE LOCAL SECTION, 8TH DECEMBER, 1913.

Mr. C. VERNIER: I think the supply of electricity for London is one of the most important and urgent problems before us at the present time. When we consider that London accounts for very nearly one-third of the present consumption of electrical energy in the United Kingdom, it is obvious that the importance of this question cannot be overrated. At the same time, it is not one of the easiest problems to solve—not from the engineering point of view, but more as a question of practical politics—since the present supply is given by no less than 64 power stations, each, with few exceptions, supplying small but very densely populated districts. The question is also further complicated by the fact that some of the undertakings are owned by municipalities and others by companies, and by the fact that the London County Council has the right to purchase the company-owned undertakings in 1931, but not the municipal ones.

Turning to the address, I think it is well to bear in mind that the author makes some important assumptions. For instance, he assumes that approximately 10 per cent interest should be provided on the capital invested, viz. 6 to 8 per cent for the investors, and 3 to 4 per cent for the sinking funds. Few will be found to question the soundness of this view, but I would merely point out in contrast that the average interest earned on the whole of our electricity undertakings in this country is about 4½ per cent, while the average placed to sinking and depreciation funds is only 2·6 per cent. Fig. 5 is very interesting, and shows that electrical energy is now being sold in London at a price which does not produce what the author has laid down as a satisfactory return upon the capital invested, while Berlin and, in a lesser degree, Chicago show up much better in this respect. The net result of the proposal outlined in Table VI is a possible annual surplus of £260,000, and a reduction of the total costs from 2·34d. to 1·96d. (item 21). To achieve this result it is necessary to spend £1,709,000 (item 22). If no better result is to be obtained, I myself do not think it would be worth while spending this large sum, and particularly facing all the difficulties. Fortunately our hope of a satisfactory solution of the London electricity supply problem does not rest upon a mere re-arrangement of the existing generating plants, but much more upon its huge prospective traction and heating and cooking load, which the author has completely disregarded in his calculations.

Turning to the question of the cables, I am somewhat surprised that Dr. Klingenberg, after boldly suggesting 100,000-volt three-phase underground cables for his long-distance transmission, thus going a good deal further than any previous suggestion that I have seen—I refer to the proposed length of underground transmission and not to the voltage—should have stopped at 20,000 volts for his ring and connecting mains. I am convinced that to-day it would be a mistake to consider anything less than 40,000-volt to 50,000-volt cables for any new scheme on the scale of that for London; and for the same load capacity a considerable saving could in this way be obtained. By using five 40,000-volt cables in place of ten cables to connect the ring mains to the power station, and two 40,000-volt cables in place of three 20,000-volt cables for the ring mains themselves, the estimated saving would be about 40s. per kilowatt on Estimate A (page 135). With regard to the proposed scheme for supplying London direct from the coalfields distant 100 miles or so, I think this question cannot be considered merely from the point of view of the possible saving that might be obtained in the cost of the electrical energy delivered in London. The question of paramount importance is the security of the supply. For this reason I think that a direct overhead transmission is quite unsuitable, except perhaps for a partial supply. If high-voltage transmission lines are ever run to London, it will be to link up the power stations there with other parts of the country. Fig. 12 suggests quite well the idea of a ring main round the whole country, with London doing its share in improving the utility and other factors of our generating plants. When we come to consider 100,000-volt underground transmission, I agree with Dr. Klingenberg that there is no difficulty in constructing single-core cables for three-phase working at that very high pressure. I should be glad, however, if he would give us some idea of what he estimates the charging current would be for a 100-mile underground transmission at this voltage and 50 frequency, and also state how he would propose to deal with it—if by loading coils at intervals throughout the route, the cost of these cannot be neglected. There are other important points arising out of the use of underground cables at such high voltages, particularly the various losses such as copper losses, due to the large capacity currents, dielectric hysteresis—both of these are continuous losses—and sheath losses arising from the use of single-core cables; there is also the difficulty of keeping the lead sheaths insulated so as to prevent circulating currents. All these would be by no means negligible on such a scheme. In conclusion, I think it would be very useful if we were to adopt the "utility factor" in our statistics. It is the only factor which enables one to determine at a glance how remuneratively the capital expended on the generating plant is being employed. It combines load factor, diversity factor, efficiency of distribution, and stand-by plant; and in view of the advisability of urging the centralization of our generating plants, it is a factor which has to be carefully watched.

Mr. H. L. RISELEY: I think it should be clearly understood that Dr. Klingenberg is only putting forward certain propositions, and that his suggestions need not necessarily be considered the correct policy as regards the bulk supply of electricity to London. With regard to the 64 stations in operation in London, I think it is probably correct to state that a very large majority of them should be scrapped, as they are nearly all obsolete and have no adequate supply of condensing water easily accessible. It seems to

* Address by Dr. G. Klingenberg (see pp. 123 and 239).

Mr. Riseley. me that too much attention has been given to the question of the supply of coal. I consider the provision of water for condensing purposes to be at least an equally important question, because it is much more feasible to transport the coal required than to find a proper supply of condensing water. Then as regards having a power station at the coalfields, this does not appear to me to get over the trouble, as everybody knows that it is quite possible for the pitmen to go on strike; also there is the possibility of fires and floods, and many other causes which would shut down the pits and thus affect the power station. In my opinion there is no advantage in having a power station at the pit's mouth. Moreover, where is there a pit or a group of pits which would be sufficient to supply the electrical requirements of London? I consider a better way would be to place the stations near the Thames and to run the main feeders east and west, not north and south as suggested by the author. There would be no difficulty in getting the colliers up the river as far as the bridges, and I do not think it would be impossible to get specially constructed steamers perhaps as far as Chiswick, since the Gas Light & Coke Company run fairly large boats up as far as Westminster Bridge without trouble, and Messrs. Thornycroft have sent down some fairly large craft from Chiswick. If, however, the colliers could not get up, no doubt specially constructed barges of, say, 5,000 tons capacity could be towed up from the coal-shipping port.

Dr. Klingenberg's remarks as to the difference in the total costs and operating costs at Berlin and Chicago are very interesting. I note that the Edison Company of Chicago has made a better bargain with the local authorities than the Berlin company; the Chicago company only pays 3 per cent of the gross receipts to the municipality, whereas the Berlin company has to pay 10 per cent. Possibly, however, it costs Chicago a lot of money to get this low rate; the sum should be capitalized and included in standing charges. I do not think the author's intricate formulæ would be of much use to engineers, but it is interesting to see the clear way in which the author brings out his results. In my opinion, at the low tariff that will have to be adopted to make the use of electricity universal there is not much chance of obtaining such an adequate return on the capital as would readily induce the public to subscribe. I think the ultimate solution of the administration of electricity supply in the metropolis will be a non-political board constituted on the lines of the Water Board or the Port of London Authority.

Mr. Turnbull. Mr. C. TURNBULL: At the end of his address the author mentions the recovery of by-products from coal. The gas-engine plant at Accrington has shown that the recovery of by-products may be successfully carried out in connection with the generation of electricity. In view of this experiment and other work now going on in this direction I think that we should hesitate before replacing existing plant by large power stations which themselves might be obsolete in a few years time when better methods have been introduced for the more efficient utilization of coal. On the other hand, it is very necessary that extensions over and above the capacity of existing plants should be co-ordinated, so that they will fit in with the large schemes which must eventually come into operation in London and other large cities.

Mr. W. McLELLAN: The wholesale supply of electricity to London is not so much an engineering problem as a political one, and it is becoming increasingly difficult every day on account of the new power stations which are being erected by the railway companies and other bodies. A previous speaker referred to the possibility of erecting at a coal-mine the generating station for supplying London; as Mr. Riseley has pointed out, however, this would be an exceedingly risky thing to do, because the coal-mine might be shut down due to accidents or strikes. Moreover, no individual mine would be large enough to supply the ultimate electrical requirements of London. At the present time something like 17¼ million tons of coal are sent each year to London, of which only about ¾ million tons are used for the purpose of generating electrical energy. If electrical engineers are right in assuming that in the future the bulk of the power and lighting (and in some cases possibly the heating) requirements will be provided electrically, it will be seen that no single coal-mine would be sufficient to provide the large amount of coal required. Mr. McLellan.

Mr. J. A. ANDERSON: In regard to depreciation and reserve, Dr. Klingenberg gives a figure of 3–4 per cent on the whole of the capital expenditure. This is more than enough for a system which is kept in first-class repair. The only parts of the system that would warrant this figure are the power stations, which may have to be scrapped in 20 or 30 years' time. As far as cables are concerned, if a company sets aside 20 per cent of the cost of the cables as a reserve fund, in 20 years' time it should have enough to meet any large replacement that may then be necessary. As to sub-station plant, it is hardly conceivable that many large replacements will have to be made within any short period, and it is not necessary to set aside any large reserve for this purpose. In connection with a general supply of electrical energy to London, a board appointed by those interested, as suggested by Mr. Riseley, appears to me to be the best means of obtaining the results that we should like to see. I think we shall all agree that a central supply authority is very essential from the point of view of economy. Mr. Anderson.

Mr. H. G. A. STEDMAN: We should have followed the author's figures more easily if he had adopted orthodox units instead of such units as "centi-shillings." A little more explanation might also have been given when defining such factors as (*a*) and (*b*) in Equations 4 and 5, and $1/n_{80}$, etc. When the comparisons with London generating stations were made, are we to understand that those at Lots Road, Neasden, Greenwich, etc., were excluded? With regard to the capital cost of generating plant and network respectively, the author draws attention to the fact that the cost per kilowatt decreases rapidly as the capacity of the generating plant increases, but that the contrary effect applies to an increase of the capacity of the network. Against this, however, must be set considerable advantages and economies appertaining to large networks. I should be much interested to have further explanation as to the assumptions which were made by Dr. Klingenberg in preparing Fig. 4, which diagram, if of general application, should be of considerable value. Another important observation is made on page 131 in connection with the utility factor, showing that, within the limits stated, the selling price can be reduced Mr. Stedman.

ian. by more than 3 per cent for each 1 per cent advance made in utilization without alteration to existing plant. The author's application of his analyses to the practical case of what may soon be one of the most important problems confronting electrical engineers, viz. the systematic supply of energy in Greater London, merits most careful consideration.

aylor. Mr. H. M. TAYLOR: The author has dealt with the existing conditions of electricity supply in three cities. He takes London as one example. The position of electricity supply in London, is admittedly unsatisfactory, and many attempts have been made to remedy it; the author does not refer, however, to these attempts, nor does he include the greater part of the London traction supply. As the figures which he gives relate to 1910–11, the recent growth of the traction supply detracts from the value of those figures. In the case of Berlin he includes traction. Again, in Table III he gives the various percentages of lighting, power, and traction. Are we to suppose that electric lighting in London at the present time accounts for 61 per cent and traction for 12 per cent of the total number of units supplied? The author takes for London the year 1910. I therefore suggest that the selling prices and other financial results given for Berlin, Chicago, and London are incomparable.

I propose to consider another English city, namely, Manchester. One reason why I choose Manchester is that although the population is not comparable with that of Berlin, the number of units sold per head of population is not very different. The comparison is as follows:—

	Manchester.	Berlin.
Population	750,000	2½ million
Number of power stations ...	3	6*
Capacity of plant installed ...	58,800 kw.	137,000 kw.
Average size of stations ...	19,600 ,,	23,000 ,,
Capital expenditure	57,410,420s.	160,426,000s.
Sinking fund, etc.	18,435,400s.	30,380,000s.
Real value	38,975,020s.	130,046,000s.
Cost per kilowatt installed ...	243s.	356s.
Cost of mains per kilowatt ...	352s.	594s.

It will be noticed that the capital outlay on the Manchester power stations is 40 per cent of the total outlay, against 38 per cent in Berlin, leaving for the network, etc., 60 per cent and 62 per cent respectively. The working results for the two cities are:—

	Manchester.	Berlin.
Total peak load	44,992 kw.	94,600 kw.
No. of units generated ...	136,820,180	274 million
No. of units sold	104,346,895	216 million
Lighting and power ...	71 per cent	69 per cent
Traction	29 ,,	31 ,,
Average price obtained ...	8·92 centi-shillings	15·8 centi-shillings
Working costs	4·83 centi-shillings	5·067 centi-shillings

In order to make the figures comparable I have deleted from item 40, Table III, the item for municipal participation. The above comparisons show that British practice is not so very far behind that of other countries.

* On page 124 the author says that a number of other stations are still working in Berlin.

Mr. J. WRIGHT: I think the author brings out very clearly one point, which forms to a great extent the basis of his figures. I refer to the development of large generating sets, in which the steam turbine has played a very important part; but for the progress that has been made in this direction Dr. Klingenberg could not have shown the figures which he has. This development has brought about a reduction both in operating costs and in capital expenditure; thus he truly states on page 125 that it is the number and not the size of the units that controls the costs. From the figures which he gives with regard to the London undertakings it is obvious that the figures would be improved considerably if some of the smaller power stations were done away with. It is rather surprising to find that the Berlin undertaking seems more economical than the Chicago undertaking, although no doubt the purchase conditions existing in America account for this. The author also states that the fuel consumption of the Berlin undertaking shows a marked superiority over those of Chicago and London stations. It would be rather interesting to know what section of the plant should be credited with this efficiency. Is it the boiler house or the engine-room? I think it must be the boiler house, as I am not aware that any of the German turbo-generators have shown any remarkable improvement in efficiency over that obtained in this country or America. I can, of course, understand that the combined London stations will not give good figures as regards steam consumption, particularly over the period which Dr. Klingenberg has taken, as up to that time many of the smaller stations were still operated with reciprocating sets which were not efficient. I do not therefore consider that the Berlin and London figures can be compared. It would be interesting to know what would be the maximum size of unit that Dr. Klingenberg would suggest installing in his station. When the stand-by plant required is taken into consideration, the size of the sets must affect to some extent the capital expenditure involved. With regard to the position of the station, and taking Dr. Klingenberg's remarks into consideration, it would seem that the ideal place for a station for London is near a colliery and an adequate water supply; in addition, such a station should be run in connection with a by-product plant, and be in an area where a traction load is likely to be developed. Such a site would of course be difficult to obtain, but the whole success of any London scheme seems to depend on being able to get a traction load. With regard to the author's estimates for coal, I notice he shows only a difference of 3s. 6d. per ton between coal at the pit-head and coal delivered into the bunkers in London. I think the difference would be rather greater, unless, of course, the much-heard-of Kent coal is used. Mr. Wright

Mr. R. M. LONGMAN: One of the chief points in the address are the equations for cost, etc. I do not think they have been arranged as clearly as they might have been, although the author has certainly obtained them in the correct way. With reference to Chicago, the fuel costs are rather high. I do not consider that American steam-turbine practice is as good as that in this country. They do not get such good efficiencies, that is, measured in lb. per kw.-hour. When we have got more big stations, I think we shall be able to show even better figures. The high capital cost of the Chicago undertaking is partly due to the fact that a large number of small stations had to be Mr. Longman

Mr. Longman

bought up. It must be remembered that in America money is worth less and is more plentiful than in this country. On page 137 why should the cost of the power station be higher with overhead transmission than with cable transmission? Again, 80,000 kw. is far too small for the main station. At Chicago a 20,000- or 30,000-kw. station was erected and immediately afterwards the construction of one of 120,000 kw. was commenced. The author has not referred to the traction load, as he might reasonably have done. One cannot help feeling rather sorry at the present time that the railways are putting down more of these really small stations. There is no set at present in London above 6,000 or 7,000 kw. capacity. Indeed, 5,000 kw. seems to be about the limit. It is a very great pity that such small units are being chosen. The arguments do not necessarily apply only to London. If a number of local authorities would supply the money in the form of debentures, it would be possible to have really large stations containing sets of 20,000 or 30,000 kw. capacity. The author has shown the possibility of using cables at 100,000 volts. There is no technical reason why 60,000- or even 100,000-volt cables should not be installed; but a large amount of energy would have to be transmitted so as to keep the cost per kilowatt to a low figure.

Mr. Marshall.

Mr. A. H. W. MARSHALL (*communicated*): I have not been able to follow the formula on page 126 dealing with the operating costs. Perhaps the author will state what the terms "a" and "b" represent in Equations 2 and 3, and also explain Equation 5, which represents the characteristic costs for an entire plant. Without a proper understanding of these expressions it is impossible to appreciate the full value of the investigations which Dr. Klingenberg has made into the cost of electricity supply in Berlin, London, and Chicago. The term "utility factor" (n) which forms the basis of the calculations is of course the plant load factor multiplied by the efficiency of distribution (m). Its connection with the load factor and spare plant, as given in Equation 6 on page 128, is very interesting. There appears to be no direct comparison in the paper between the selling prices in the three cases with reference to the respective load factors; and this after all is what is required in order to know whether energy is relatively dear or cheap. From the figures given, the load factor at Chicago appears to be 36·6 per cent and the selling price 1·09d. per unit; Berlin 26·1 per cent and 1·9d. per unit; and London 19·6 per cent and 2·34d. per unit. These prices are astonishingly high, even with the relatively poor load factors.

In his estimates for the reconstruction of the London undertakings, I think the author would have done well to assume a greatly increased traction and power load, comparable as regards the proportion of lighting, traction, and power, with that in Berlin. His figures would look very much better if they took into account the large extensions which a reconstruction of the undertakings with the improved facilities would undoubtedly bring about. The addition of further traction and power load would improve the load factor and thus the utility factor; and an improvement in the utility factor would react on the price and develop a vastly greater market, tending on the whole to improve the business in an accumulative manner. If a reasonable allowance were made for such an increase of load, the scheme of reconstruction would be more attractive to investors. As it is, the figures show a saving of £260,000 on an expenditure of about 1¾ millions of capital—a saving of about 15 per cent after paying interest on new capital. It should be noted, however, that the rate of interest allowed is only that obtained at present, which owing to the nature of the business is perforce lower than the holders of the existing capital desire. Additional capital would require a higher rate of interest and probably a more liberal depreciation charge than that allowed. It would probably be well to reduce the surplus by a figure representing a further 5 per cent on the new capital, which would leave about £174,000 to be divided amongst the 25 existing undertakings as their share in the benefits of any reconstruction scheme. I do not know how far this would be sufficient when it is considered that these 25 undertakings have at present a capital of £21,763,000, and that the legal and other difficulties necessary to bring about such a change as is proposed would be immense. With, however, an increased power and traction business—which would undoubtedly be developed if the reconstruction were undertaken on the lines suggested—and a utility factor approaching that of the power companies in this part of England, the estimates would make a much more attractive proposition for the reconstruction scheme. In regard to items Nos. 18 and 19, Table VI, the low-tension network losses after conversion are less than they were previously. I do not see why this should be so, seeing that new cables are being laid down, and presumably the existing feeders will remain for distribution purposes. On page 136 Dr. Klingenberg proposes purchasing a strip of land for the main transmission lines at about £11 per acre. I consider that such a figure is far too low.

Dr. Klingenberg.

Dr. G. KLINGENBERG (*in reply; communicated*): Mr. Vernier does not consider the estimated result (item 26, Table VI, page 141) of replacing 22 of the existing power stations by one large station sufficiently encouraging to warrant its being carried out on the lines which I have indicated. It appears to me that he has omitted to take account of the fact that item 14 in Table VI includes, apart from depreciation, 6 per cent, or £102,540 per annum, on the new expenditure necessary to effect the reconstruction, and that after paying 8 per cent (interest and depreciation) on the existing capital, £362,540, *i.e.* about 21 per cent per annum, would therefore be available for dividends on the new expenditure. For a solution of the problem Mr. Vernier looks to the combination of the existing stations with a traction load; but it must be admitted that such an amalgamation is out of the question unless the economy of the stations giving a general supply has reached that of modern traction power stations. The solution proposed by Mr. Vernier is therefore subject to such alterations as those which I referred to in connection with Table IV. I omitted electric heating and cooking because at present this load is exceedingly small compared with the other loads which I have considered, and in consequence there are at present no reliable data of general value with regard to the load curve, diversity factor, etc. I should therefore have had no reliable basis for my figures as in the case of light, power, and traction.

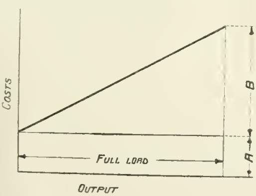
I have read with great interest Mr. Vernier's views with regard to the pressure that should be used in the case of cables laid in cities; such an opinion expressed by an engineer with his experience will certainly carry great weight.

Dr. Klingenberg.

My conservatism as regards the pressure (20,000 volts) to be used for the cables in the London area was mainly due to insufficient acquaintance with the exact local conditions. A pressure of 40,000 or 50,000 volts will in all probability necessitate the use of single-core cables, which are more expensive to lay than three-core cables; further, with such pressures the space required for the sub-stations rapidly increases. As the laying of the cables and the space required for sub-stations generally form a large proportion of the total cost in the case of large cities, the advantage of the extra high pressure is more quickly nullified in such cases than with cable systems in the open country. The charging currents for the 100,000-volt trunk cables are very large. With a frequency of 50 ∿ and 3 single-phase cables per circuit of the size which I have taken, the power required for charging amounts to about 700 k.v.a. per kilometre. To avoid this I have assumed that choking coils are provided at the end of every 50 kilometres (about 30 miles) of such a capacity that they balance 80 per cent of the charging current. These choking coils, together with the necessary switchgear, increase the total cost of the main and auxiliary cables by about 3·5 per cent. A large amount of energy is lost in such cables compared with the cables used up to the present time, but owing to their large carrying capacity their efficiency is quite satisfactory even in the case of long distances (see the differences in the efficiencies at various distances in Fig. 10).

I do not consider Mr. Riseley's and Mr. McLellan's objections to the power station at the pit's mouth, namely, the risk due to strikes, are justified. In the first place, I take it for granted that a large city will obtain its electricity supply from several power stations, and therefore from more than one colliery. Secondly, a strike at such a colliery would not endanger the electricity supply unless other collieries and the transportation companies also took part in the strike and thereby stopped the coal supply altogether. But this it must be admitted is a risk which has to some extent to be faced wherever the power station is placed, whether near or distant from the respective cities.

Mr. Stedman's and Mr. Marshall's requests give me a welcome opportunity for further explanations of my equations for the cost characteristic. The equations are based on the simple fact that the relation between the output and the charges affecting the selling price of electrical energy is approximately as shown in the diagram herewith :—



namely—

$$\text{running costs} = A + B \times \text{output} \div \text{full load} \quad . \quad (7)$$

A and B being constants, of which A represents the cost of operating and maintaining the plant at no load (no-load losses, standing capital charges, etc.), and B the difference in the costs between no load and full load.

Let n = utility factor over a year,
L = full-load capacity of the plant,
K = yearly running costs per kw.-hour,
$a = A/L$ = no-load costs per killowatt,
$b = B/L$ = increase of costs per kilowatt.

Then Equation (7) can be written as follows :—

$$n \times 8{,}760 \times L \times K = 8{,}760 \times L \times a + n \times 8{,}760 \times L \times b \quad . \quad (8)$$

or the yearly running costs per kw.-hour—

$$K = \frac{1}{n} \times a + b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

For machinery such as boilers, generators, etc., the constants a and b can easily be determined by actual tests with varying loads. Other items such as repairs, general expenses, etc., have to be found from the yearly statistics. Generally the statistics for these items only give the value K at a certain utility factor n; to determine therefore the absolute values of a and b, it is necessary to estimate in such cases the ratio $a : b$ (see Table V, page 140). The relationship is not quite so simple for finding the average cost of fuel for a power station with a number of sets, because apart from the characteristic of each individual boiler, turbo-generator, etc., the no-load costs depend on the number of hours for which each unit has been run during the whole year.

Let K_w = average annual cost for fuel per kw.-hour generated.
$L_1, L_2, \ldots$ = full-load capacity of the various sets,
$s_1, s_2, \ldots$ = yearly running hours of the various sets,
Z = number of sets installed,
n = utility factor of the power station,
a_w and b_w = constants in connection with the fuel consumption, as explained above.

Then Equation (8) reads as follows—

$$n \times 8{,}760 \times \Sigma(L) \times K_w = 8{,}760 \times \Sigma(s \times L) \times a_w + n \times 8{,}760 \times \Sigma(L) \times b_w \quad (10)$$

Therefore—

$$K_w = \frac{1}{n} \times \frac{\Sigma(s \times L)}{8760 \times \Sigma(L)} \times a_w + b_w \text{ per kw.-hour} \quad (11)$$

If all the sets are of equal size—

$$K_w = \frac{1}{n} \times \frac{\Sigma(s)}{8760 \times Z} \times a_w + b_w \text{ per kw.-hour} \quad . \quad (12)$$

It will be seen that the expression $\frac{\Sigma(s)}{8760 \times Z} = f$, represents a well-known factor, namely, the ratio between the actual running hours per annum of all the sets and the maximum possible number of running hours. With this simplification the average cost for fuel in the power station is expressed by the equation—

$$K_w = \frac{1}{n} \times f \times a_w + b_w \text{ per kw.-hour} \quad . \quad . \quad (13)$$

Dr. Klingenberg

From the definition given above, it is evident that f lies between a maximum value $= 1$ and a minimum value $= n$.*

In the calculations for my address I assumed in all cases for f the mean of the limiting values, namely, $f = \frac{1}{2}(1 + n)$. Substituting this in the above equation we obtain—

$$K_w = \frac{1 + n}{2n} \times a_w + b_w \text{ per kw.-hour} \quad . \quad . \quad (14)$$

This is identical with Equation (3) on page 126 in my address if the constants there given are multiplied by the cost of fuel.

As regards Fig. 4, the load factor diagram for any desired combination of light, power, and traction, the values taken have been obtained by superimposing in various combinations the fundamental values for light, power, and traction, from the load curves of Fig. 1. Examples of such superimposed curves are given in Figs. 2 and 3, and it will be found that the load factors in those figures are identical with the values obtained from Fig. 4 at the respective values of r_k and r_b.

I have read with interest Mr. Taylor's data relating to Manchester, which are characteristic of a plant with exceptionally low capital costs (the total being 595s. per kilowatt installed) and average overall efficiency (about 7 per cent); but as I have previously explained (see page 243) the purpose of my address was not to compare power plants on the basis of the best records of working costs, and I will therefore refrain from further remarks on those figures.

The difference in the economy of the power stations in Berlin and Chicago is, I believe, due to a certain extent to less efficient machines, but mainly to the higher superheat used in Germany. According to my information it was the practice in Chicago at the time to which the figures in my address refer not to exceed a temperature of 250° C., whereas in Berlin steam temperatures between 300 and 350 C. were used.

I wish to support Mr. Marshall's views with regard to the importance of taking into account prospective developments when reconstructing a plant, and I consider the cost characteristics and the load factor curves (Fig. 4) an essential help in this respect. For instance, in the example of the reconstruction of a number of London stations, I gave on page 135 the cost characteristics both for the new station (B4) and the remaining old stations (C3). To determine the influence of an increased traction load compared with the existing combination of light, power, and traction (Table III, items 17, 18, and 19), I would refer to the load-factor curve in Fig. 4, from which the corresponding improvement of the load factor, and therefore also the approximate improvement of the utility factor, are found. This value substituted in the above equations for the cost characteristics (C3 and B4, page 135), determines the new average price to be charged for energy after allowing for a normal return on the capital outlay, eliminating thereby a great deal of guesswork which is generally connected with such calculations for future developments.

The smaller losses in the low-tension network after reconstruction (item 18, Table VI), to which Mr. Marshall refers, are explained by an increase of the utility factor after the reconstruction (item 8, Table VI), which again is due to the smaller reserve (item 7, Table VI) permissible with large plants, as stated in my address at the bottom of page 129. The difference in the cost of the losses (item 19, Table VI), which is obtained by multiplying the losses by the generating costs, is still greater, since the generating costs are also considerably decreased after the reconstruction. With regard to the price which I allowed for the land for the overhead line, I would refer to my reply on page 149 to Mr. Snell's criticism.

* Further details in connection with the influence of this running-hour factor (f) on the cost of fuel in power stations will be found in my book dealing with the design of large power stations.

DISCUSSION ON

"ELECTRIC TRAIN-LIGHTING SYSTEMS."*

MANCHESTER LOCAL SECTION, 27TH JANUARY, 1914.

Dr. E. ROSENBERG: There can be no doubt whatsoever that electric lighting is incomparably safer than gas lighting for trains, and that the tanks containing compressed gas under the carriages do not increase the safety of the travelling public. The most remarkable statements, however, are made in discussions on train lighting. I once heard that compressed gas, instead of igniting, would even blow out a lighted match held in front of a puncture in a tank. I will not combat the possibility of such an experiment, but unfortunately the actual experience of railway collisions shows that the gas not only becomes ignited but also sets fire to the woodwork of the train, and that the fire spreads with great rapidity. After the Aisgill disaster an engineer who took a prominent part in the rescue work gave quite clear and impressive evidence of the part which the gas tanks played in that disaster: he was engaged in gas-engine work, and presumably was therefore not greatly prejudiced in favour of electricity. In the discussions that arose out of that disaster, a very prominent person stated that according to information which he had received, but not checked, there was not a single electrically-lighted coach on either the German or Austrian State Railways. This statement is without any foundation. Although the large majority of the coaches are still lighted with gas, there are hundreds of electrically-lighted coaches on the Prussian railways, as well as on practically every other German railway, and the same remark applies to the Austrian railways. One high official of the Prussian State Railway, namely Geheimrat Wittfeld, was prominently associated with the development of a train-lighting system mentioned in the paper (the Buttner system), which has since made rapid progress and is now also used on a number of other railways. I can speak from first-hand knowledge on that point because my machine, which is described in the paper, is used in that system. The French State Railways have taken up the question of electric lighting on trains very vigorously, and strong action was taken after the recent collision at Melun, where the gas caused a very serious fire.

The author's comparison of constant-voltage and constant-current systems is of great interest. I would say, however, that strictly speaking there is no constant-voltage or constant-current system. The systems of Stone and the author, for instance, are constant-torque systems, and therefore try to give a current in inverse proportion to the momentary voltage of the battery. In the so-called constant-voltage systems the voltage must be made to rise gradually from approximately 2 volts per cell to the charging voltage, say, 2·4 volts per cell. It must also be considered that regulators do not work with perfect accuracy, and that in some systems the inaccuracy of the regulator due to friction, heating of the coils, and other causes, may be so great as to create a difference in the voltage quite comparable with that in the so-called constant-current systems due to the gradual increase of the voltage during continued charging. The inaccuracy in the so-called constant-current systems, due for instance to varying belt friction and other causes, may also cause greater differences in the current than occur in the so-called constant-voltage systems due to the reduction of the current during the continuous charge. There is one very interesting constant-voltage system designed by Mr. Woodbridge, of the Electric Storage Battery Company of America, which is specially distinguished by the omission of any kind of lamp regulator or resistance between the battery and the lamps. Mr. Woodbridge uses a pressure of only 2·25 volts per cell. He claims that this voltage is high enough to keep the battery well charged and to maintain it in perfect order, and that this voltage, on the other hand, is low enough to prevent the gradual increase in the illumination proving uncomfortable to the eyes of passengers when the battery voltage rises from its normal to this figure. I have not ridden in a car fitted with this system, but the statement seems perfectly feasible, considering how little one notices, when reading in the dusk, the gradual reduction in the illumination, which amounts at that time to many per cent every few minutes.

The Electric Storage Battery Company uses instead of a voltage regulator a very interesting arrangement, which is shown in Fig. A herewith. For the generator a modification of the Rosenberg machine is used, which the author has mentioned in Messrs. Mather and Platt's system. The field winding comprises a series winding, which is just strong enough to compensate for the armature reaction, and a shunt winding which takes a very small current and is connected as one diagonal of a Wheatstone bridge. Two arms of this bridge, namely a and d in Fig. A, consist of iron wires in bulbs filled with rarefied hydrogen, while the two other arms, b and c, are represented by ordinary resistance material. The other diagonal of the bridge is connected to the terminals of the generator (in parallel with the battery). The resistance of iron wire when the latter is near dull-red heat increases enormously

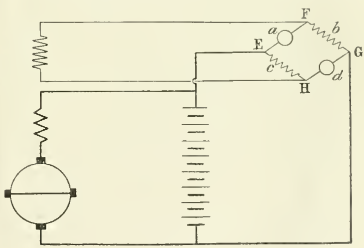


FIG. A.

* Paper by Mr. T. Ferguson (see p. 262).

Dr. Rosenberg. as the temperature rises. The iron wire, for instance, can be calibrated for 1 ampere so that it will give, say, a drop in pressure of 2 volts across its terminals when the current falls to 0·99 ampere, and if an attempt is made to increase the current, the resistance will increase so rapidly that the voltage may rise 10 volts, whilst the current actually returns to 1·0 ampere after momentarily rising slightly above 1·0 ampere. Therefore, if the voltage of the generator is slightly below its normal value, causing the current through the Wheatstone bridge to fall slightly below its calibration value, the voltage drop between the points E and F of the bridge and between the points G and H will be very low, and the exciting voltage for the shunt winding will not be much less than the battery voltage. With the smallest rise of the battery voltage, however, this exciting voltage will be reduced considerably—even down to zero. The machine will therefore not perceptibly change its voltage whatever the increase of speed may be. This system has been used very successfully on the Santa Fé Railway.

The statement on page 264, that "with most double-battery systems the efficiency is probably not more than about 5 to 10 per cent of the current generated," seems to me to be very remarkable, and I cannot possibly believe that it refers to systems which provide a definite current independent of belt slipping and graduated in accordance with the momentary lighting load. With reference to Fig. 4, a statement as to the value of the charging current would be valuable. The dynamo efficiency of 65 per cent mentioned on page 266 seems to be a fair figure if it includes the belt losses in systems which work without belt slipping. In describing his own very interesting system the author refers to an overcharge preventer which breaks the dynamo field. I should like to know whether this procedure is also followed when the lights are on. It is quite possible that on very long non-stop runs the state of the battery might reach the "gassing" point even if the lights were on; breaking the field would then mean that during the remainder of the journey the battery would have to feed the lamps and that the battery might therefore become discharged again. That would be a disadvantage compared with other systems in which the output can be exactly adjusted by changing the excitation, and where the overcharge preventer can be arranged so as to reduce the excitation to such a value that the dynamo current is then just equal to the lamp current.

Mr. Denham. Mr. J. DENHAM: The author refers to several cases where overcharge preventers are used, but I should like to know if overdischarge preventers are employed at all on the various train-lighting systems now in general use. It is possible to imagine cases where the battery would run right down, *i.e.* below the generally accepted minimum voltage of 1·8 volts per cell, if carriages were being cleaned and were left all night with all the lights on owing to careless cleaners; or a carriage might be used for many hours on a foggy day and night running slowly and with many stops, so that the battery would receive little charge and would give frequent discharges. It must be very detrimental to the battery if such cases of "running down" can occur in any way periodically.

Mr. Cooper. Mr. F. E. COOPER: Speaking from the point of view of the "man in the street," there is no doubt as to the great danger which arises due to the illumination of trains by gas. It was certainly a revelation to me to learn from this paper what a large number of electric train-lighting systems had been developed, and like Dr. Rosenberg I hope for the complete displacement of gas for train lighting.

Mr. Pope. Mr. A. POPE: There is one system which the author has not referred to and which I think is a very important one, namely, the straight storage system. From the battery makers' point of view this is probably the best system, and I think that in many cases it is also the best system from the user's point of view. Where trains have to run over a distance of say 12 to 15 miles, and charging facilities can be provided at one or both ends of the line, a small battery only need be used. Whatever may be the state of charge of the two batteries, I think it is impossible for one battery to discharge into the other, since immediately such a current passes the back electromotive force of the low battery will rise and stop the flow of current. On page 264 the author refers to curing a sulphated cell by running it in service. I think a cell when it gets into that state should be taken out of service and put into the shops for proper treatment, which it cannot receive in service. With regard to the small voltage variations on the battery, an increase of 5 per cent in voltage reduces the life by about 50 per cent, and even a $2\frac{1}{2}$ per cent increase in voltage will reduce the life by about 30 per cent. This is a point which the users will probably consider important.

Mr. McKinnon. Mr. E. C. McKINNON: I have had at various times to report on numerous systems of train lighting, and one of my pleasantest experiences was a tour in 1906 through Germany and Bavaria to investigate and report on the Rosenberg system. I was impressed at the time by the great difference in the care which was taken of the batteries in Germany—and at a later visit, in Scandinavia—compared with that in this country. In my report I emphasized this point and advanced the opinion that however satisfactory the results of any particular system might be, it did not follow that these results could be repeated in this country owing to the conditions of working. Let me quote from the report:

> "In Germany and Bavaria the railways are State controlled, and the careful operation of the batteries is deemed of equal importance with the rest of the plant, all of which is minutely supervised. The batteries are properly examined once a week. In this country, however, batteries so far have been a very neglected part of railway equipment. From our own experience we know that the regulation period for opening up a battery to examine it properly is in some cases six months, and instances are on record where a coach has been lost for several weeks. Then again it is doubtful if the railway companies would agree to incur the expense entailed by the provision of distilled water for topping-up purposes, whereas no other water than distilled is used in Germany and Bavaria."

That is 8 years ago. Since that time the working conditions here, although still very far from ideal, have greatly improved. In a recent catalogue of one of the makers

whose system has been described by the author I find under the section dealing with cells the following statement : "Provision is made for inspection and testing, also for taking the specific gravity and keeping the cells in a fit and proper condition"; but on the other hand the catalogue also states that "Attention at very infrequent intervals only is required to see whether on the whole the battery is over or under charged." This can only be construed into an invitation not to trouble very much about the cells. The catalogue further states that when the coach is running with no lights on, a small charging current is passed through the battery to make up for the polarization losses. This is very bad practice, because it is the small current which is able to attack the positive plates and which by unnecessarily reducing them to lead peroxide shortens their life. A rough comparison of the method of assembling the cells shows the heavy handicap under which they are worked in this country. The British standard is a set of cells each in a lead-lined wooden box fitted with a bolted-down lid, the whole being placed in a wooden case slung under the body of the coach. To obtain access to the cells when in service it is necessary to crawl under the coach, remove the side of the outer case, disconnect the bolted connections, lift out the cells, and unscrew the lids, the whole operation being carried out while in a kneeling position. In Germany, however, the cells are in ebonite boxes which are held in a wooden case in sets of four, the cases being iron-bound at the bottom corners. The boxes are fitted with loose lids resting on the plates. The battery compartment is fixed directly under the body of the coach, and the footboard in front of the compartment swings up and is held in that position by a small bracket. The compartment is fitted with one or more locks ; and by unlocking the compartment the front swings out, forming a shelf, on which the containers can be drawn so as to be at once ready for inspection. It should be noted that inspection under these conditions is so easy that the attendant assured me he makes it a practice of examining the battery after every second trip which the various trains make, although his instructions are that he need only do so once per week. In Denmark, axle-driven systems are not in common use owing to the number of ferries on the main routes, and straight battery lighting is employed. The battery is assembled on racks in a special battery compartment on the conductor's coach. Each cell can be examined readily at any moment whilst in ordinary service. On page 267 the author states that any of the constant-current systems can be maintained by comparatively poor-class labour. On page 263 he says that traffic conditions demand that a poor class of labour must be able to maintain the equipment ; this I think is the keynote to the question of battery depreciation. In England, rule-of-thumb methods, indifferent attention, and crude switchgear are the custom, and if anything goes wrong the battery is blamed. In Germany we find splendid organization and close attention, and if anything goes wrong the mechanic is blamed. Dr. Rosenberg referred to Mr. Woodbridge's statement that a pressure of 2·25 volts would maintain a cell in proper condition in train-lighting service. I think a point has been missed here, namely, that the cell must be kept healthy. If the cells are once allowed to become sulphated, through standing idle or discharged for long periods, such a voltage will not restore the cells to a healthy state, and the system would therefore probably be a failure under the ordinary conditions on British railways. I do not agree with the author in his arguments on page 264 against the double-battery system, especially the statement that the fully-charged battery will probably discharge into the empty battery, with consequent double losses.

Mr. McKinnon.

Mr. Stansfield.

Mr. W. Stansfield : The author in referring to the Dalziel train-lighting system recommends that the special magnetic circuit should be dispensed with and differential coils introduced into the exciter, an iron-wire resistance being inserted in circuit with one of the above coils. I am particularly interested in that suggestion, since in conjunction with Mr. Hatt I developed a train-lighting system on somewhat similar lines and obtained some very promising results with experimental machines. We found that by connecting the exciter to the main machine at one pole, and by connecting the differential coils so that the one with the iron-wire resistance was across the main machine and the coil without the resistance was across the free ends of the main machine and the exciter (see Fig. B herewith),

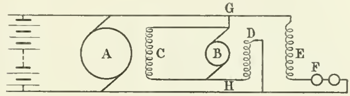


Fig. B.

almost any characteristic could be obtained, from one in which the voltage rose as the speed increased, to a characteristic in which the voltage fell after it had risen to its maximum (Fig. D). Dr. Rosenberg has mentioned

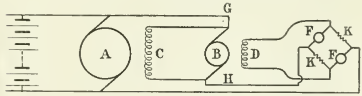


Fig. C.

the combination of the Mather and Platt machine with a special Wheatstone bridge. We also experimented with this special bridge in connection with our machine and obtained some very fair results, but as far as we went the differential coils proved the better arrangement. I might mention that in order to leave us with as free a hand as possible with our coils, in the majority of our experiments we did not use iron wire but ordinary metal-filament lamps, and found that the large increase of resistance from cold to hot (an increase to about 10 or 11 times the cold value) was quite ample for our purpose. Figs. B and C indicate how the special arrangements should be made. In Fig. B, A is the main armature, B the exciter armature, C the main field coil, D and E the differential field coils on the exciter, F the iron-wire (or metal-filament lamp) resistances. On reversal, the connections at G and H should also be reversed. In Fig. C, A, B, and C are the same as in Fig. B, D is the field coil of the exciter, F F are iron-wire or metal-filament lamp resistances, K K are resistances

Mr. Stansfield.

(such as carbon lamps) having either no variation with temperature or else having a negative variation. The

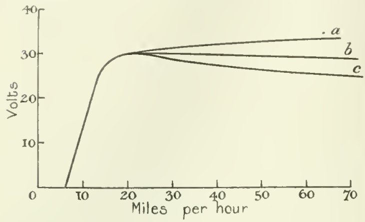


FIG. D.

connections G and H are to be reversed on reversal as in Fig. B.

Fig. D represents three characteristic curves, indicating the possibilities of the arrangement. To obtain these the initial excitation voltage is varied, *a* having a lower initial voltage on the exciter relative to the main voltage than *b*, and *b* a lower one than *c*. Assuming a constant voltage across the main machine an increase of speed demands a reduced excitation voltage, which inevitably gives an increase of voltage difference between the main and exciter machines—the two machines being connected so that the voltage across D or the bridge is the difference between the main and exciter voltages. This increase of voltage is the governing margin required, and it will readily be seen that the larger the proportion that B bears to A, the larger is the proportional variation of voltage for governing, and the characteristic curves change from *a* to *c* (Fig. D). In the majority of our experiments, and in the arrangement which we finally decided upon, we actually connected our load across the two machines A and B in series, but in this case the A and B voltages were added together and the governor coil was connected across A only. By this means the voltage of A was permitted to rise, this slight rise being compensated for by the corresponding drop in the voltage of B. Ultimately we combined A and B in one machine, and on this machine we were able to obtain a perfectly level voltage curve from the lower limit up to the mechanical limit of the machine. A ratio of 2½ to 1 at no load, and 2 to 1 at full load, were the results, the full and no-load voltages being the same. This was without using batteries. Our experiments were carried out on an ordinary 4-pole machine with the armature wound as a 2-pole drum. If any members are interested, I would refer them to Patents Nos. 12,704, 20,764, 22,500, all of 1908, and 4,181 of 1909. Unfortunately, owing to the very unpromising state of the market for electric train-lighting machinery at the time we did not feel justified in maintaining the patents and they have now lapsed.

In his communicated remarks Mr. Newton states that he did not think the action of the machine would be decisive enough in building up on account of the weak field of the exciter. As a matter of fact the machine actually builds up its electromotive force correctly and with much greater promptitude than an ordinary shunt-wound machine. This will be understood when it is considered that the iron-wire resistance being cold has a similar effect to short-circuiting the field resistance of an ordinary dynamo.

Mr. Dalziel.

Mr. J. DALZIEL (*communicated*): While the author has made a very useful contribution to train-lighting literature, I think the interest of the paper might have been increased if he had gone a little more fully into details with regard to the various systems. In particular, a more exact description of the principles of operation of the system with which he has been associated—namely, the Leeds Forge Company's system—would have enhanced the value of the matter relating to this system. I deal more fully with this later. The paper gives me the impression of having been written rather from the point of view of the electrical engineer than from that of the railway man, and I think some points which are considered of importance by the latter have been missed by the author. For example, on page 263 it is pointed out quite correctly that the services on which a coach may run often vary considerably in respect to the amount of lighting current demanded; to meet this it is stated, under No. 2 of the list of requirements, that some definite means of adjustment of the output is necessary. Unfortunately, while practically every system provides for some such adjustment, when the service of a coach is changed, on the one hand it is only very rarely that the maintenance staff can be advised of the change of service and thereafter have access to the coach for such adjustment, and on the other hand it is only by guesswork that even an approximately correct adjustment can be made. In actual practice if the change of service is from a light to a heavy current demand, the necessity for adjustment automatically shows itself because the lights go out for lack of dynamo output; whereas if the change is from a heavy to a light demand, no such notice of attention being required is given, and the result is persistent battery overcharge and damage to the cells. As the author has missed this point it is not surprising that he has also missed the sequential one that the preponderating advantage and recommendation of the constant-voltage system are that it removes the whole of the necessity for adjustment, and that it transfers from the battery to the infinitely more robust dynamo the whole of the wear and tear of operation and regulation, and obviates practically all liability to either over- or under-charging.

As the author quite correctly points out, the rise in the counter electromotive force of the battery itself is the overcharge preventer with this system, and since with it the rate of charge of the battery obviously depends entirely on its state of charge, and the charging current is also entirely independent of whether lights are in use or not and of any other conditions of dynamo loading, clearly it is also the best system by which to ensure immunity from undercharging and sulphating. Furthermore the heavy current that passes into a discharged battery ensures a very much more rapid recovery to a condition of healthy charge than can be the case with any constant- or limited-current system. Also as this system ensures, in a way that no other system can ensure, that only such current as is actually required for lighting and charging, and no more, is produced, the power demand on the locomotive is and must be less with this than with any other system. The insertion of resistance, as suggested by the author, is quite a good expedient to limit the initial charging current and

Dalziel give a tailed-off charge effect, but this, though simple, is not necessary with the small battery capacities that are amply sufficient with this system in this country. It is an expedient that is useful on occasion, however, more particularly in America, where capacities of 400 to 600 ampere-hours per coach are used—and necessarily used—and where consequently a tailed-off charging system is not only the one that is best suited to the conditions, but is essential if the generator capacity is not to be excessive. The loss of efficiency in such a resistance is low enough to be practically negligible. The author is hardly fair in attributing the comparatively small use—at present—of constant-voltage systems to a recognition by railway engineers of the inferiority of the principle. He must recollect that until the present writer advocated this principle and designed a regulating method that could be employed in train lighting to give a constant voltage independent of the battery, no such system existed. This was when constant-current systems had been many years in the field and were more or less established, and the new system has had to combat the innate and quite proper conservatism of the British engineer, which for well-understood reasons is nowhere more in evidence than in electric train lighting. Furthermore, in this country the last few years have been no time for developing electric train-lighting systems, old or new.

With regard to gassing, I think the author is mistaken in alleging that gassing does not take place at, say, 2·5 volts or even lower voltages per cell. Gassing does take place, though not with the violence which accompanies it at, say, 2·7 volts per cell ; it is persistent gassing with full charging current at some such voltage as the last mentioned that with constant-current systems boils away the acid and causes the plates to deteriorate. As regards such gassing being necessary to keep the plates healthy, in my view the function of gassing is simply to circulate the acid and maintain it at uniform density throughout its height. The motion of the train in combination with the gassing already mentioned as taking place even with constant-voltage pressures is sufficient to ensure this. As a proof of this contention I may instance that the original equipment on the Dalziel constant-voltage system is running on the Midland Railway to-day with the same battery with which it commenced to run 8 years ago, and this battery though it had to come through all the experimental period with its inevitable troubles is still good for a year or two's life.

With regard to the difficulty in removing the sulphate when a constant voltage is used, this is a perfectly legitimate objection, but owing to the favourable treatment of the battery as above indicated, the occasions when sulphate that requires removal is allowed to form with a constant-voltage system are almost non-existent. As a matter of fact, experience shows that in a day or two the constant-voltage system satisfactorily overcomes sulphating using only the normal voltage ; but if desired it is easy of course to raise the voltage slightly. While on this question of sulphating, I should like to ask the author what becomes of the overcharge-preventing relay in his and other constant-current systems while the operation of removing the sulphate is in progress, seeing that such relays are necessarily operated by a rise of voltage ? It appears to me that unless this device is put out of action the dynamo will perpetually cut out, and sulphate will never be removed, Mr. Dalziel. which is an infinitely worse state of affairs than with constant-voltage charging and is one of the principal arguments against the use of such overcharge-preventing relays. Most of the latter that I have seen have evidently suffered the same fate as many overload preventers on motor starters, *i.e.* they have been tied up out of action to prevent them from giving trouble.

Reverting to the Leeds Forge Company's system, I have never been able to understand how the alleged regulating device of this system operated so as to provide even approximately constant-current regulation, and the author's description makes this no clearer to me ; if he can elucidate my difficulty in his reply to the discussion I shall be indebted to him. The point is that while it is alleged that regulation is accomplished by means of the torque required to drive the armature—an increase of which forces the armature out of the field and so reduces the flux passing through it—and while obviously the regulation is a constant-torque one, it appears to me that with this means of regulation only it is inevitable that the current must rise very considerably as the speed increases. This is due to the fact that as the flux traversing the armature becomes reduced the torque per ampere must also inevitably be reduced ; and following on the constant-torque principle the current must, as stated, considerably increase, as well as the power taken to drive the machine. The only further regulation that I can see is that due to armature reaction, which will increase in effect with the increased lead given to the brushes as the speed rises. I make this point having due regard to the claim made by the author that with this regulation the magnetomotive force in the air-gap increases rather than decreases as the speed rises, which of course contradicts my supposition, but I can see no other alternative. If this really does effect the further regulation it would, I think, be simpler to cut out the mechanical feature and trust to the electrical feature alone, thus giving a fairly simple, purely electrical machine, as, for example, in the Siemens-Wright system.

Though the author in his system has paid me the compliment of imitating my double-switch arrangement for switching in the dynamo of a single-battery system and my arrangement of using the discharge current from the battery to the lamps for holding down the lamp switch until the dynamo is quite ready to take over the duty, I cannot believe that the further additions made to the lamp switch are an improvement. It seems to me that the system must be subject to very considerable sudden variations due to the operation of the lamp switch. Taking place constantly, as apparently they must do at intermediate speeds, these variations are extremely objectionable. This in fact is the experience which I had of the system on the only coach equipped with it that I have ever ridden on ; the continuous flickers and jumps caused me to look for the main switch in the corridor to find out whose equipment it was. I am also inclined to think that the end cells will eventually suffer considerably.

With regard to the author's suggestions for improving the constant-voltage system that bears my name, I am afraid that the hot iron-wire resistance has proved too unreliable a piece of apparatus for the proposed exchange to be worth considering ; in fact, as the author is probably aware, such resistances have already been used in series

Mr Dalziel with the lamps for absorbing excess voltage, and have also been proposed as a means of regulation. I believe that in the first-mentioned use they have not been particularly satisfactory, and I have not heard of the last-mentioned going much beyond the experimental stage as yet. It would of course be possible to use permanent magnets in place of the constant excitation winding, but I hardly think it would be advisable.

I do not wish to discuss any of the other systems except the Grob-Pintsch. It seems to me that if the batteries get run down they have not much chance of ever picking up again, and certainly will not get up at all quickly, which is entirely the reverse condition to that of the Dalziel constant-voltage system. Furthermore, with a very fully-charged battery as a regulator there would appear to be a tendency to overcharge the other battery, with of course the reflex effect on the first-mentioned battery when a change-over takes place. The former is of course considerably the more serious possibility. It is also a great disadvantage that two batteries are required with this system.

Mr Lundberg Mr. G. C. LUNDBERG (*communicated*): No reference is made in the paper to providing facilities for the partial control of the light by the passengers. Assuming that the actual switching on or off of the light throughout the train must be under the control of the guard, it is essential on main-line trains that passengers in individual compartments should be able to dim the light when they wish to rest. There is no need, however, to adopt the usual wasteful method of leaving all the lamps full on and obscuring them by means of movable shades. Various tumbler-switch controls have been devised for controlling the amount of light, namely: (*a*) 2 lamps in parallel or series; (*b*) 2 lamps in parallel, 1 lamp only, 2 lamps in series; (*c*) 3 lamps in parallel or series; (*d*) 3 lamps in parallel, 2 in series, 3 in series; (*e*) 4 lamps in parallel or series. Methods (*a*) and (*b*) are suitable for compartments lighted by 2 lamps, methods (*c*) and (*d*) for compartments with 3 lamps, and method (*e*) for 4 lamps. In each case there is only one tumbler switch of ordinary size per compartment, and this —as has already been stated—can only vary the amount of light, the supply to all compartment switches being controlled by the guard. Methods (*b*) and (*d*) have the advantage of giving three degrees of light; and as regards method (*e*) it may be stated that the light given by 4 metal-filament lamps in series would not be too dim for some people. One or two methods are being used in which the lamps are dimmed by resistances contained in the switches; and although such methods find favour in some quarters, I am inclined to think that the above series-parallel methods constitute good alternatives.

Mr Newton. Mr. C. A. NEWTON (*communicated*): There is no doubt that the careful attention paid to the treatment and maintenance of the battery or batteries used in train-lighting systems is justified, since on this depends to a very large extent the success or otherwise of any train-lighting system. In connection with the author's description of the Dalziel constant-voltage system, and the treatment accorded to the battery in this system, I would point out that provision has already been made for the use of the series resistance mentioned by the author; and this resistance can be connected in such a manner that the regulation of the lamps is in no way affected. This would be effected by connecting the series resistance between the top contact of No. 2 switch, directly above the terminal marked B +, and B +. It will be seen that with this connection of the series resistance and a consequent higher charging voltage and increased lamp resistance, the system could be readily adjusted so that the voltage on the lamps would not vary when No. 2 switch cuts in; also the series resistance would be in circuit with the battery while the latter is charging; and with both No. 1 and No. 2 switches cut out, the lamps would be directly connected across the battery as before. I may say, however, that it has been found in practice that the battery treatment is all that could be desired without the use of this resistance. In certain cases, however, where a very large storage capacity is required, compared with the actual lamp current, this resistance would be an advantage by allowing a smaller dynamo to be used; and, as pointed out above, since this resistance would not be in circuit with the lamps when the battery discharges, its inclusion would only affect the overall efficiency to a very slight extent indeed.

With regard to the use of a hot iron-wire resistance and a plain magnetic circuit for the exciter, I should like to draw attention to the fact that such a machine was provisionally patented in this country some four years ago, and as this machine does not appear to have been developed, the natural conclusion is that such a machine is not very practicable. Even if the same degree of regulation could be obtained with the use of a wire resistance as suggested, the absolute certainty of building up with a constant polarity when the machine is rotated in either direction (this is at present an important feature of the Dalziel constant-voltage machine) would be very materially prejudiced, and indeed it is doubtful whether a machine arranged with this method of excitation and without any independent source of excitation could be depended on to build up at all, since the degree of saturation in the magnetic circuit of the exciter would in any case necessarily be of a very small order. In the patent specification of the Dalziel dynamo mention is made of the possibility of using a permanent magnet in place of the highly saturated pole. The objections to this, however, are: (1) the very much decreased magnetomotive force available from such a magnet, and (2) the necessarily much increased weight to obtain the same flux-carrying capacity. In connection with the former objection, I would mention that the relationship between the magnetomotive force expended upon the highly saturated pole and the reluctance of the armature and air-gap portion of the magnetic path is of considerable importance, as affecting the fineness of regulation. I may say that on one of these sets which has been in service for 8 years the original battery is still in use.

Mr Ferguson Mr. T. FERGUSON (*in reply*): Dr. Rosenberg refers to the Stone system and the Leeds Forge Company's system as constant-torque systems. I would point out, however, that the former is a constant-torque system but that the Leeds Forge system is a variable-torque one, the torque being inversely proportional to the speed. Both systems should give lower current output toward the completion of the charge as the battery voltage rises; that is to say, the charge is tapered off. This is a very desirable feature, and in this respect both these systems are superior to the electrically-regulated systems described, in which the charging

current increases toward the completion of the battery charge. I quite agree with Dr. Rosenberg that no system really gives constant current or constant voltage. One is apt at first sight to form a partiality for the constant-voltage system, as it would appear to be only common sense that the lamps should burn on a constant-voltage circuit; whereas, as Dr. Rosenberg points out, the variation in any so-called constant-voltage system is probably as great as in the constant-current system.

I am most interested to hear about Mr. Woodbridge's experiments on the Santa Fé Railway, where the charging voltage is limited to 2·25 volts per cell (that is to say 12½ per cent above the normal lamp voltage) and no compensation is used in the lamp circuit. This is a fairly large range of voltage to subject the lamps to, and rather a low pressure to charge batteries at, but I have no doubt that it works satisfactorily. Whether or not it would prove expensive in lamp and battery renewals could only be settled by some railway company having courage enough to adopt it on a sufficiently large scale to give it a fair working trial.

With reference to Fig. 4 in the paper, the charging current is the 8-hour charging rate.

With reference to the Leeds Forge overcharge preventer, I would say to Dr. Rosenberg that the railway companies have the option of arranging to cut the preventer out of service when the lamps are burning. Even if it were not cut out of action, and it operated on a journey, by the battery becoming fully charged, it is not likely that the train would run continuously without a stop or without slowing down for more than one or at the most two hours after the overcharge preventer had operated, so that only part of the charge would be taken out of the battery. The overcharge preventer resets itself when the speed of the train falls below a certain limit. The object of arranging it in this way is for simplicity, and I do not think that any real benefit is sacrificed by so doing.

In reply to Mr. Denham's remarks, so far as I know over-discharge preventers are not in general use either in this country or to any great extent abroad.

The straight storage system referred to by Mr. Pope has been used for a long time past in this country as well as abroad. It certainly has never become popular, and this is probably because of the lack of flexibility of the system. With reference to battery troubles due to sulphating, it is often impossible to remove a battery at once to the shops for treatment, and it is my experience that the trouble can be at least partially cured by running the battery in service under constant-current conditions. With regard to the life of the lamps, my experience with the Leeds Forge Company's system is that one can get from two to three years' life out of modern metal-filament 24-volt lamps, and I doubt also whether any system would keep the voltage much within the limits mentioned by Mr. Pope without undue complication of the system. With so long a life as that mentioned, the maintenance cost for lamps is not a serious matter.

I think that the care and treatment of batteries on British railways has improved greatly in recent years, and hence the contrast between Continental and British practice is not so marked. Mr. McKinnon comments on the reference in the paper to poor-class labour. It is a fact, however, that a system must be able to be maintained and cared for by poor-class labour if it is to be a commercial success in this country. I quite agree with Mr. McKinnon that Mr. Woodbridge's proposal to use a pressure of 2·25 volts per cell for charging would necessitate that the cells be kept healthy; and if they are allowed to become sulphated, due to standing idle or other cause, this voltage would probably not be sufficient. Mr. Ferguson

Mr. Stansfield's contribution is very interesting. His results reply very fully to several points discussed by Mr. Newton and Mr. Dalziel and need no further elaboration on my part. I am sorry that Mr. Stansfield did not go further into the train-lighting problem and develop the rest of his system. I think he has abandoned a most interesting and fascinating subject.

With reference to Mr. Dalziel's remarks, I quite agree that when the service of the coach is changed it is very seldom that the maintenance staff can be advised in time of the proposed change. However, even if the adjustment is not attended to beforehand, no harm results, and it is an easy matter to adjust the output at the first available opportunity, an operation requiring in modern properly-designed constant-current machines at the most not more than two or three minutes. Theoretically, the constant-voltage system should remove the necessity for adjusting the dynamo, but I doubt very much whether in practice it is possible to operate a constant-voltage system without adjustment of some sort; and such adjustment, as mentioned in the paper, has got to be much more delicate and is by no means so definite as it is in the constant-current system. In fact, as I have pointed out, the constant-current system is the more robust and easily handled of the two. I cannot altogether agree with Mr. Dalziel that the constant-voltage system is the best system to ensure immunity from undercharging and sulphating, especially with a battery which may have been left lying about in a discharged condition for some time. Neither do I agree with him that the power demand on the locomotive must be less with the constant-voltage system than with any other; as obviously when the state of the battery is low the current from the dynamo is very large, which obviously demands considerable power from the locomotive. I am glad that Mr. Dalziel agrees that the insertion of resistance in the charging circuit is a good expedient, as when resistance is inserted a rising charging-voltage characteristic is obtained, somewhat similar to that of a constant-current system, a point on which I laid considerable stress in various parts of my paper. Mr. Dalziel states that he has had his system in operation for eight years, and also that I am hardly fair in attributing the comparatively small use of constant-voltage systems to a recognition by railway engineers of the inferiority of the principle. However, the fact remains that during the last eight years several fresh constant-current systems have been introduced, some of which have been taken up moderately well, whereas had the constant-voltage system been the best, surely that would have been recognized and substantial orders placed during the past few years.

With regard to "gassing," I cannot see that I have stated it does not take place at 2·5 volts per cell, or even at lower voltages. I only said that at least 2·5 volts per cell is necessary in practice to keep the battery in good condition. I cannot agree that the only function of gassing is to circulate the acid, neither do I agree that

Mr. Ferguson.

the motion of the train would do this automatically in train-lighting systems, as the spaces between the plates in most types of train-lighting cells are filled up by wooden separators, which would practically prevent circulation of the acid from the motion of the train.

With reference to the overcharge preventer, this is set at a voltage which is high enough to allow the ordinary current to pass in a sulphated cell, and it has not been my experience that properly-designed overcharge preventers in constant-current systems are useless.

Mr. Dalziel says that he cannot understand how the "alleged" regulating device in the Leeds Forge system operates; he also states that obviously the regulation is a "constant-torque" one, and that he can only account for the regulation by the armature reaction. If this were so, Mr. Dalziel would be quite right in assuming that it would be preferable to cut out the mechanical feature and use a normal machine. However, the regulation is a "variable-torque" one, and so both the current and the power are kept constant. In fact, by suitably shaping the cam a drooping characteristic can easily be obtained. I think this will now make the action perfectly clear to him. It is a very simple matter to calculate the variable slope of the cam, the formula being—

$$\tan \theta = \frac{63000 \times \text{h.p.}}{\text{r.p.m.} \times R \times r},$$

where θ = the angle of the cam corresponding to the r.p.m.,
R = the resisting or controlling force of the spring,
and r = the radius of the cam.

There is nothing arbitrary in this formula; it is a simple question of mechanics, and checks out correctly in practice.

I must confess to being quite innocent of imitating Mr. Dalziel's double-switch arrangement. According to my earliest experience of train-lighting apparatus, dating back a long time before Mr. Dalziel described his system, two such switches were used, and it has always been quite common practice in single-battery systems. Further, I would point out that I do not hold down the lamp switch by a solenoid or magnet of which the winding carries the discharge current from the battery, as in the case of Mr. Dalziel's system. I cannot understand either Mr. Dalziel's theory or his experience in connection with the frequent jumps and flickers in the light. It has not been my own experience and I have heard of no such complaint from the various railway companies both at home and abroad who are using the system.

Mr. Ferguson.

I understand that hot-wire resistances are found quite successful where they are used. They certainly complicate a system and produce a loss of power where they are employed as lamp regulators, as I pointed out.

I quite agree with Mr. Dalziel that if the batteries in the Grob system become run down they have a poor chance of picking up again.

As regards Mr. Lundberg's statements, I would mention that the control of individual lamps by passengers is quite usual in first-class compartments, sleeping-cars, etc., but it is not usual for railway companies to provide means for dimming the lights. This is purely a question of expense in additional wiring, switches, lamps, etc., and, as Mr. Lundberg says, it presents no particular difficulty. The possibility of switching individual lamps in and out is referred to in several places in the paper, and it has not been assumed that the switching on or off of the lamps throughout a train must be under the control of the guards.

I am interested to learn from Mr. Newton's communication that he makes provision for a series resistance in the charging circuit of the battery, and I would add that I am a firm believer in the use of resistances in the charging circuit when charging from constant-potential mains, whether it be in train-lighting systems or for charging portable batteries from the ordinary electric supply mains in a house. I consider that the benefit received more than counterbalances the slight loss involved. With regard to Mr. Newton's remarks as to the modification of the exciter which I suggested in the paper, I may say that Mr. Stansfield appears to have obtained excellent results from this device. I was unaware of Mr. Stansfield's experiments when I wrote my paper, and the results of those experiments as described in his remarks provide a complete reply to the latter half of Mr. Newton's communication.

Birmingham Local Section, 28th January, 1914.

Mr. Taylor.

Mr. A. M. Taylor: I should like to draw attention to the low efficiency of the batteries used for train lighting, especially when a double-battery system is employed. Having regard to the low efficiency of train-lighting systems, it is not surprising that there is such a large increase in the draw-bar pull or decrease in the speed of the train when the lighting apparatus comes into operation.

Mr. Fennell.

Mr. W. Fennell: I should be glad if the author would state whether it is still the custom of railway companies to judge the suitability of a battery for train-lighting purposes by its capacity for withstanding persistent over-charging. In this connection I may mention that I knew of a case some years ago in which the merits of a battery that was submitted to a railway company were decided by such a test, and this seems to confirm the very low efficiency of train-lighting systems.

Dr. Coales.

Dr. J. D. Coales: Would not the installation of a battery in each coach and generators only in the guards' vans meet the ordinary traffic conditions on a railway? Such a plan is obviously much simpler and cheaper than that in which a train-lighting dynamo and the accompanying switchgear are provided in each coach. When a carriage had to be slipped at a junction the battery would look after its lighting for the time being in the usual way, and the battery would receive its charge during the time the carriage formed part of a complete train. Such coaches could not of course be included for any lengthy period in, say, a local gas-lighted train, but that difficulty would disappear when electric lighting on any system became general.

Dr. Garrard.

Dr. C. C. Garrard: In my opinion modern train-lighting systems appear to be unnecessarily complicated.

rgan. Mr. J. D. Morgan: The development of the principal train-lighting systems appears to be characterized by an excessive accumulation of corrective accessories. A defect in the dynamo or battery is corrected by the addition of some device designed to prevent that defect from operating adversely in the lighting circuit. Frequently the accessory introduces a further defect, and this is rectified by another accessory, thereby bringing about the accumulation of corrective accessories. I wish to emphasize the necessity of the designer's reviewing the fundamental requirements of the problem and endeavouring rather to develop systems inherently satisfactory than to gain perfection by complicating a system which is fundamentally defective. In connection with the question whether the ideal generator system should provide constant voltage or constant current, I wish to point out that the requirements of the lamp circuit demand a constant voltage and variable current. Unfortunately this is not capable of attainment by ordinary means, because the requirements of the battery are incompatible with this condition. The designers of train-lighting systems have become so obsessed by the difficulties arising from the use of a battery that the problem is no longer how to light a train but how to charge a battery. It is for this reason the constant-current system has been generally adopted. The unsuitability of the constant-current system is becoming more and more widely recognized, and serious efforts are being made in a number of directions to realize an ideal constant-voltage system.

on. Mr. T. Ferguson (*in reply*): In reply to Mr. Taylor's remarks, I would say that the storage batteries used in train-lighting systems are not in themselves inefficient, and need not be a greater source of loss than the ordinary power-station or sub-station battery in an electricity supply system. Double-battery systems may certainly become a considerable source of loss, especially when one of the batteries becomes short-circuited by dirt, loose paste, or due to other causes. It is occasionally noticed in electrically-lighted trains that the light decreases in brilliancy while the train is running, and increases, for a short time at least, while the train is standing. This is what occurs when the No. 2 or lighting battery contains a faulty cell. When the train stops the two batteries are connected in parallel, and the lamps get the benefit of the good battery. The extra draw-bar pull due to the dynamos in the case cited and illustrated in Fig. 5 in the paper is only about 4 per cent of the total locomotive draw-bar pull in the case of the constant-efficiency system, and would be less if the train was run at all during the hours of daylight. With the belt-slipping system the draw-bar pull is considerably greater, as explained in the paper. Mr. Ferguson.

In reply to Mr. Fennell's remarks, I do not know of any special storage-battery tests that are generally adopted by the railway companies, other than a prolonged trial in service.

I quite agree with Dr. Coales' statements, but the system which he mentions does not appear to have found favour with the railway companies owing to the subdivision of trains for different services. The connectors between the carriages would involve extra work in uncoupling, and practically every guard's van in the system would have to be fitted with generating plant. There are also various other reasons too numerous to be discussed in detail, which would prevent this system becoming popular.

In connection with Dr. Garrard's remarks, it has been the aim of every designer of train-lighting apparatus to simplify the system without impairing its reliability, regulation, and efficiency.

With reference to Mr. Morgan's remarks, I think he is unnecessarily severe in condemning the present systems as being "fundamentally defective." Mr. Morgan states that the "unsuitability of the constant-current system is becoming more and more widely recognized." If this be so, then why is it that the modern constant-current systems are being adopted in greater numbers than the constant-voltage systems? Possibly the answer is to be found in Mr. Morgan's own remark that the requirements of the battery are incompatible with that of the constant-voltage system.

DISCUSSION ON "SOME RAILWAY CONDITIONS GOVERNING ELECTRIFICATION."*

BEFORE THE INSTITUTION, 12TH FEBRUARY, 1914.

Mr. Firth. Mr. H. W. FIRTH: I am so much in agreement with the author that I find little to criticize in this paper, which has been written from the railway point of view. There are, however, a few points to which I should like to call attention. In the first place, the author emphasized what is the greatest drawback to electrification in this country, *i.e.* the low return for passenger transportation. That is a matter which cannot apparently be dealt with by the railway companies themselves. Fares have gone down, and are now at an extremely low figure, many of these low fares being statutory obligations upon the companies. The position is this, that the railway companies are expected to provide, for precisely the same revenue as that which they are now obtaining, the higher acceleration, the better schedule speed, and the superior comfort that are features of electrical services. If 100 per cent load factor were obtainable on suburban services, it would be possible to get an adequate return from electrification, but unfortunately by far the greater part of the suburban business is dormitory business, in fact peak-load business. It is not necessary in speaking to members of this Institution to emphasize what that means in regard to the economics of the position. To provide a very large capital for peak-loads, *i.e.* rush-hour traffic, and to have that capital lying more or less idle during the rest of the day, is not good business. Electrification has frequently been shown to increase greatly the number of passengers carried, but some of the figures which have been published in regard to the results of electrification must, I think, be taken with a certain amount of caution. Where there is a good steam suburban service it is not possible for electrification to show such good results as in some cases where a comparatively poor steam suburban service has been electrified. Then, again, the character of the district very materially affects the return which can be obtained from electrification.

There is one point which the author has referred to and where I think he is not quite correct as regards suburban services; he says that "with electrification a maximum of 48 trains per hour can, if required, be run each way during the rush hours while employing existing stations and tracks." I myself do not think there is any general trunk-line railway system in this country which will accommodate 48 trains per hour each way while employing existing stations and tracks. The limiting factors, as the author said, are not engineering factors; they are well known. The limiting factors in suburban electrical working are the question of finance, to which I have just referred, and the question of traffic working. As many as 48 trains per hour could certainly not be worked over the majority of the flat junctions or into most of the termini in this country; and certainly not in the case of London. In that connection the author says on page 295: "Most of the suburban services into and out of London already provided or in process of being provided are run on tracks distinct from the main line." If that is so, a very frequent service can be worked, but I do not think 48 trains per hour can be run continuously, even under conditions like that. That rate may be obtained for a quarter of an hour or so, but I do not think it can be kept up continuously under the conditions of a trunk line. Very often there are heavy gradients; in many cases speed restrictions round curves; and in the majority of cases, even if the line can be more or less set aside for suburban work, it is bound at some point or another to conflict with main-line trains or with goods trains or other services, and I think that such a figure as 48 trains per hour will not be attained in practice under the ordinary conditions on trunk lines. In my opinion there is one very important point, not only as regards main-line working—in which connection the author has referred to it—but also as regards suburban working, and that is the point which he makes as to the necessity of obtaining a motor with a speed characteristic different from that of the series motor. That point is very important indeed for this reason: it is not possible to restrict certain rolling stock always to certain definite services. It may be necessary one day for the rolling stock to be worked on a schedule which requires station stops 0·8 or 0·9 of a mile apart; but the next day it may be necessary for that train to run at 60 miles an hour on a semi-express trip. Unless it is proposed to duplicate the rolling stock that point requires attention. As regards many of the lines running into London which have a very heavy seaside traffic in the summer and a very heavy suburban business as well, it will be found that on Bank Holidays and on Sundays in the summer a very large proportion of seaside traffic has to be dealt with by suburban stock, and if that stock is to be electrified and if it is proposed to electrify sufficiently far out to accommodate any of these services, the problem will have to be faced of obtaining a motor which will work adequately on both those services. I think it is very important that more attention should be given to the problem of either separately exciting the field or devising some method of giving a more flexible speed characteristic to the motor. I am sure that is very important in many cases, even as regards suburban traffic.

There is one other point in regard to dealing with heavy traffic on which I think the author is not quite correct, namely, where he mentions as among the advantages multiple-unit-controlled motor-coach trains. He says that among the other advantages are "first the doubling of terminal accommodation by halving the number of signal and locomotive movements." I do not think that is quite right. A number of locomotive movements are done away with altogether, and the signal movements are halved or perhaps even more than halved, but the accommodation is not thereby doubled, although no doubt it is largely increased. I saw some figures the other day with regard to the Berlin Stadtbahn line in which it was shown that under electric working the number of trains possible on the clear section of the line not complicated by junctions or terminals was 40 per hour in each direction with electric traction, and 32 per hour in each direction with

* Paper by Mr. Roger T. Smith (see p. 293).

rth. steam; but at the terminus it was found that 33 electric trains per hour and 21 steam trains per hour were all that could be worked. What may be called the "terminus factor," that is to say the relative number of trains which can be dealt with at the terminus compared with those which can be dealt with on the through line, is for electrical working about 0·825, and for steam 0·656, taking the above figures. Thus it is impossible to double the number of trains that can be worked into a terminus by adopting the multiple-unit equipment or in any other way; in fact, it is, as I say, the terminus working and the flat junction working which militate against running the number of trains per hour which one would like in order to increase the suburban business as it should be increased.

As regards long-distance traffic—passenger traffic particularly—I think the author has shown very plainly that, for the time being at any rate, the problem is not one which we can hope to tackle. He has shown that, even if we obtained the locomotive with the necessary characteristics, we are still faced with the problem that, as far as can be seen under the present conditions as regards the cost of coal, the cost of electrical energy, and, what is perhaps equally important, the cost of money, there is very little likelihood of being able to save in operating expenses, and it is not likely much advantage will be obtained.

With regard to goods working, there again I think some of the points made by the author must be taken with a little reserve. He points out what is obvious, that the electric locomotive can give a very much greater train mileage per annum in service than the steam locomotive can. He refers, however, to the fact that an increase in the size of the goods trains may be impossible until the lay-by sidings, etc., have been increased; but I think it ought to be emphasized also that it is no use providing a locomotive which is capable of running, say, 50,000 miles per annum unless the service conditions and the track conditions allow of that being obtained. There are many traffic schedules in operation in this country—necessarily in operation because of other services and because of the lay-out of the lines—which do not call for a greater mileage of engines than can be done by a steam engine under present conditions. Of course the electric locomotive is going to be much more economical; it will not have any stand-by costs while it is idle. But I do not think it will be found to be possible always to get in general goods service the amount of mileage out of a locomotive which is theoretically possible; and that will affect the cost per train-mile which is given in the paper. I do not say it will affect it very much, but I think in some cases it will be a factor which has to be considered. I think that the author's summing up of the position as regards goods working is quite accurate, with the above exceptions, but I do not imagine that heavy goods working will come into operation in this country at the present time except in places such as on the North-East Coast where the conditions are exceptional. The mineral traffic on the North-East Coast is, as no doubt the majority of members know, a thing which is quite apart from general railway working in this country. In a position like that it is quite possible that electrification will come about in a very short time. But I think general goods electrification is in the same category as general passenger electrification, and that neither of those branches of the work is a matter with which we are likely to deal at the moment. On the whole, as I say, I am in agreement with the author's remarks, and I think it is a very good thing indeed that the members of this Institution should have the opportunity of discussing a paper which does not deal with the matter from any controversial electrical point of view, but purely from the point of view of the general broad policy of the electrification of railways. Mr. Firth.

Mr. Sparks. Mr. J. B. SPARKS: When we contrast the rather unfavourable remarks of the author and of Mr. Firth with the electrification work now in progress in London and elsewhere, we can only come to one conclusion: that electric traction and steam traction for suburban work cannot be compared directly as regards operating expenses. Electric traction gives something which steam traction cannot give, and in order, therefore, to compete successfully with tramways and omnibuses or to increase the capacity of any given line, it may be absolutely necessary to adopt electric traction. In the first part of the paper the author refers to the possibility of using one system of electrification for suburban lines and another system for the main-line traffic. Surely it would be very difficult to work a railway under those conditions, with locomotives of two different electrical systems and two different kinds of supply. In the case of the supply, for example, there would have to be two separate power stations, or alternatively rotary transformers for single-phase supply in addition to the rotary converter plant for the continuous-current supply. With regard to the relative importance of the cost of electrical energy, the author takes the fixed charges of railway operation at 60 per cent and the variable charges at 40 per cent, and states that of this 40 per cent electric energy in a particular case formed three-fourths, *i.e.* 30 per cent, of the whole. But decreasing the cost of electrical energy by one-half surely reduces the total working costs by 15 per cent only, and not 25 per cent as he suggests. At any rate I should like to know to what that 25 per cent refers. Further, I think the figure of 75 per cent, *i.e.* the ratio of the electrical energy to the total variable costs, is too high. In the case of the Central London Railway it is only 40 per cent; and in the author's own estimate for main-line working the 3d. per train-mile given is only 40 per cent of the total of $7\frac{1}{2}$d. per train-mile. In that case reducing the cost of energy by one-half would reduce the total operating costs by only 8 per cent. It is important that one should appreciate the correct proportion of the energy cost, as in all probability railways will not be able to purchase electrical energy at much less than 0·4d. per unit with present methods of generation. The author's figure of 0·33d. is certainly within the range of possibility, but I do not think his 0·25d. is. The 1913 contract of the Commonwealth Edison Company of Chicago with the Chicago Railways for a supply of some 60 million units, with a maximum demand of 20,000 kw., is equivalent to 0·45d. per unit; and even if the maximum demand reaches the enormous figure of 120,000 kw., or say 360 million units per annum, the price falls only to 0·354d. That is for a very large station with a 40 per cent load factor.

With regard to main-line working, the author takes the example of a line with an annual traffic of 10 million train-miles over 1,000 miles of route. Assuming double

Mr. Sparks. track, or 2,000 miles of track, this represents an average of 5,000 trains per annum over any section of the track. Taking the full 8,760 hours per annum as the number of hours of running, this gives an average service of one train every $1\frac{3}{4}$ hours over a 24-hour day, or one train every $1\frac{1}{4}$ hours over an 18-hour day. That is surely a very poor service, and one would hardly expect to obtain much economy by adopting electric traction for such a service. Taking his estimated saving of 3d. per train-mile, the author concludes that with this service the saving is sufficient to pay 6 per cent on a capital expenditure of £2,100 per mile of route. For a continuous-current equipment of 2,400 volts, I estimate that an amount sufficient to pay the cost of the track equipment and sub-stations for, say, a train service every half-hour would be about £5,500 per mile of route. If the author's total of 10,000,000 train-miles is multiplied by the ratio of £5,500 to £2,100, we get the number of train-miles which, at 3d. saved per train-mile, will provide sufficient to pay interest on that amount. The result is 26,400,000, which corresponds to a train every 40 minutes over a 24-hour day, or a train every 30 minutes over an 18-hour day, which is approximately the present service over the Brighton line. With this train frequency, therefore, electrification would just pay for itself. Mr. Philip Dawson has stated that by placing all the Portsmouth trains on the Brighton line he would get a service of one train about every 15 minutes. On the basis of the above figures it would appear that there would be a saving in that case, because if one train every 40 minutes over a 24-hour day just pays for electrification, a train every 15 minutes would probably give a reasonable profit, providing, of course, that the traffic demands such a train frequency.

There is one point which I do not see mentioned in the paper, namely, that if electrification is carried out there is a saving due to the elimination of coal haulage. In the paper by Mr. Kahler before the American Institute of Electrical Engineers, which is mentioned by Mr. Roger Smith, it is assumed that there is a reduction by electrification of 4·6 per cent in the number of ton-miles per annum, due solely to the absence of coal haulage over the system. Mr. Kahler takes the number of train-miles per annum for electrical working as only 75 per cent of the number in the case of steam working, partly on this account and partly due to the increase in the weight of the trains which is rendered possible by the ability of the locomotive to haul heavier trains over the ruling grades. With regard to the author's ratio for the mileage of steam and electric locomotives, I find that he takes 27,000 miles for the steam and 40,000 miles for the electric locomotive, *i.e.* approximately a 50 per cent greater mileage in the case of the electric locomotive. Mr. Hobart assumes the same ratio in his paper, to which the author's refers, but I find that Mr. Kahler in the case of passenger locomotives takes 55,700 miles for steam and 107,000 miles—nearly twice as much—for electric locomotives.

With regard to Mr. Firth's remarks, surely it is admitted that the electric locomotive will spend only a short time in the shops, and that there will be comparatively no cleaning to do; further, the cleaning that is required need not necessarily be done in the engine-house. In that case, for a given service, considerably fewer locomotives would be required. In most cases the number of electric locomotives would be less than 75 per cent of the number required for the same service with steam locomotives, and so the number of train-miles for the electric locomotive would be at least 30 per cent greater than the number for the steam locomotive. The actual records which have been published for the electric locomotives on the Pennsylvania Railroad and the New York Central lines, both terminal electrifications, are very disappointing, however. The 1912 average for the 33 Pennsylvania Railroad locomotives is only 30,000 miles, while the average for the New York Central Railroad with 47 locomotives is 28,800 miles. These poor results are, I think, due to the traffic conditions on those lines. There is a short run of only 9 miles in the first case, and a shorter run still in the second. The passenger locomotives in the case of the Pennsylvania Railroad, however, gave in some cases 54,000 miles per annum. Mr. Sparks.

There is one question which I should like to ask the author; how does he obtain the figure of $7\frac{1}{2}$d. per train-mile? Assuming that the cost of electrical energy represents 3d. per train-mile, and with repairs at £200, or 1·2d. per train-mile—which is very low, since it is 1·6d. in the case of the Pennsylvania and New York Central lines—and with interest and depreciation at 6 per cent, which on a £5,000 locomotive represents £300, or 1·8d. per train-mile, it leaves only 1·5d. per train-mile for wages and administration, which is much too low a figure.

Dr. S. P. SMITH: In this paper the author has brought Dr. Smith very fair criticism to bear upon many of the problems connected with the electrification of railways. There are some points, however, that might well have been touched upon, to enable us to form a judgment somewhat more easily. For example, the reasons that have led certain railways to adopt electrification are among the most important questions which we have to consider. It is certainly not an economic question in every case. Even if economic advantages are expected, they are in some cases a secondary matter. In a country like ours, rich in coal and without the opposing influences of water power, it might be a strong argument that, unless it was economically sound to electrify a railway, electrification should not be considered. On the other hand, from what the author has told us, it is certainly not economical advantages alone that are bringing about the electrification of many suburban lines. It would be well if we could have a synopsis of the reasons that have led other countries to adopt electrification. For instance, the reason for the equipping of the experimental line at Dessau–Bitterfeld in Germany was stated to be not so much a question of economics as the necessity for dealing with the increasing traffic on that particular section, which reduced itself to a choice between doubling the track and speeding up the traffic; the latter could only be done electrically. In other cases where there are heavy gradients and long tunnels, such as are met with in Switzerland and Italy, the question is not primarily an economic one, because electrification is really the only solution of the problem at the present day. It is only necessary to mention the Giovi Tunnel in Italy, where the air became practically unbreathable; but now that the railway has been electrified it is possible to deal with the traffic in a satisfactory manner. Again, there is the recent case of the Lötschberg Tunnel, which was constructed from the outset as an electric railway.

In our own particular case, it seems to me that one of the greatest needs in the future will be the terminal electrification of the lines around great cities, and I am sorry the author does not mention this subject specially. It is quite possible that in the near future many of or all the main lines will haul all their long-distance trains electrically into London. At a certain point outside London where the suburban electrified lines start, the steam locomotive will probably be taken off and an electric locomotive attached. It may be that in time railways will be compelled to do this by law, or on account of the fines for allowing engines to emit smoke becoming so excessive. Or, indeed, the companies themselves may find it beneficial to electrify termini where the upkeep of the tunnels due to the effect of the smoke and the corrosion of the rails and steelwork are excessive, and valuable space is required for coaling, etc. This seems to me to be one of the things that is bound to come, just as the electrification of suburban lines is bound to come.

There is another point that I should like to have seen brought forward, and which I think ought to be strongly impressed on all who are interested in the electrification of railways, namely, that the argument for the self-contained unit is one of the strongest reasons in favour of the existing method of operating trains. When it is only a question of a few miles in and around London this may not be so important, because if the service can be supplemented by an existing steam service an alternative is at hand. But if we do away with the self-contained unit, it seems to me that we may be lowering the factor of safety of working to an undesirable extent. Though one of the strongest arguments at present for the retention of the steam locomotive is doubtless the fact that it already holds the field, we have nevertheless to remember that a line that is electrified can easily be put out of service. This strategic argument is one that has been considered for a long time on the Continent, for a sharpshooter aiming at one of the insulators could put a whole section out of work; or, in a country where there are strikes and industrial unrest, it is only necessary for one of the insulators to be damaged to interfere with a lot of traffic. All these things have to be considered in connection with the factor of safety of working. It may be that under normal conditions the system would be quite sound; but we are not living under Utopian conditions. To my mind, this matter should be mentioned in a paper dealing with the conditions governing electrification.

The only other point to which I wish to refer is in connection with the limits of the electric locomotive. Whether it is a sound economic proposition to use the electric locomotive for long-distance work I am not concerned with, because I am not competent to speak on this side, but the author makes the statement that he does not think it is possible to develop 1,100 h.p. from an electric locomotive at 70 miles per hour. In order to see if this is so I have made some comparisons with the Lötschberg Railway locomotives, which I think are some of the finest and most successful electric locomotives that have ever been built. The first question is: Can one get the required power at the desired speed electrically? Now in a single-phase commutator motor this is only a question of voltage control. By merely adjusting the pressure the motor can be made to work at any speed that may be required. The starting torque is also purely a matter of control, and there is no need to make the motor exert a starting torque that will break the drawgear. I think that everything could be arranged quite satisfactorily electrically by merely controlling the voltage in the proper manner. Turning now to mechanical details. I took the dimensions of the two 1,250-h.p. motors, the gears and the diameter of the driving wheels, and then worked out two corresponding 550-h.p. motors intended to drive the locomotive by helical gearing at the required speed of 70 miles an hour. I first increased the size of the driving wheels from 4 ft. 6 in. to 6 ft. 9 in., which is, I think, about the normal size on British express locomotives. The gear ratio on the existing locomotive is 1:2·23—this I reduced to 1:2, and thus increased the speed of the gearing by 10 per cent, which I thought permissible, for the present gearing is working quite satisfactorily at 3,000 ft. per minute, with a maximum peripheral speed 50 per cent above this. The new motor was also designed to run at 4 times synchronous speed. As a result, I found that the diameter of the motor was such that it just enabled me to get the gears between the axle of the motor and the counter axle. That was quite a straightforward calculation, and it seemed to me there would be no trouble whatever in making such a locomotive run at 70 miles an hour and develop 1,100 h.p. The question of the bogies does not concern me, nor am I able to say how much adhesive weight could be allotted to the driving wheels at this speed; these are questions for the mechanical engineer. Dr. Smith.

With regard to a question discussed by the author in connection with the economical side, I have to acknowledge the courtesy of Professor Dalby in permitting me to show two interesting slides on the screen. The one illustrates the efficiency that can be obtained from a steam locomotive and the other that from an electric locomotive. From 100 heat units obtained from the coal, it is seen that in the steam locomotive only 5 per cent of the heat units are converted into mechanical energy. Of this, 1 per cent is needed to overcome the friction of the locomotive, and 4 per cent remains for hauling the train. The other slide shows the electrical case where the 100 heat units are provided at the central station. The efficiency of 10 per cent given by the engine would probably be objected to by most engineers of large stations at the present day. The system is practically the same as we have on our underground railways, and shows that here again we get some 4 per cent of the energy available for traction. That means, according to this rather pessimistic comparison, that the electric train would be no more efficient from the point of view of energy than the steam train. Accepting this basis, we have now to see what it means. It is just a question of what has to be paid to get the 100 units of energy. The author tells us that on the locomotive they have to pay twice as much for the coal as the central station has to pay; so that, according to this figure, if the calorific value is the same, the electric train is getting its energy at half the price the steam train gets it at. This of course is only a rough comparison and takes no capital charges into account, but as far as the cost of energy alone is concerned, it may be interesting.

Mr. W. M. Mordey: As affecting the prospects of electrification of railways the author emphasizes two requirements—one that locomotives should be cheaper— Mr. Mordey.

Mr. Mordey. that is a question of capital cost—the other that energy should be cheaper—that is a question of working cost. I want to confine myself to the second of these points; but regarding the first of them I would ask the author in his reply to give some figures showing what proportion of the total capital cost of electrification must be allocated to the locomotives, so that we may see what difference it would make to the total expense if he got his locomotives at half the present price. The author's demand for cheap energy—he mentions 1/8d. per unit—is getting very familiar to us. No doubt cheap energy is very desirable, but perhaps too much attention may be given to it. I suggest it might be as well to go a little further back and see what is done with the energy when it is obtained. Could not the author attain his object of reducing the total cost of energy by making better use of the energy when he gets it? An examination of the curve in Fig. 1 may be useful in explaining what I mean. It shows that the number of watt-hours per ton-mile increases very much as the stations get nearer together. What does this curve mean if we express it in terms of efficiency? Allowing for the not unreasonable assumption of say 10 lb. per ton friction loss on railways, then the best figure in the curve, namely, 40 watt-hours per ton-mile with stations one mile apart, means an efficiency of 50 per cent, and the lowest figure in the curve, 93 watt-hours per ton-mile with stations one-third of a mile apart, means about 19 per cent efficiency. I do not know where these lowest figures in the curve come from, but I do know that on carefully working out the results some years ago for the Liverpool Overhead Railway I found the same sort of thing. There they had frequent stations, and high positive and negative acceleration. The loss in starting resistances was about 20 per cent, and the loss in braking about 50 per cent. These losses did not include any line or transmission losses. Energy is poured into the train to get it up to speed as fast as possible and is then shut off, and the brakes are applied and the train stopped as quickly as possible—very difficult conditions to meet of course, but we may hope that the author and others who have opportunities may find some way of avoiding this very serious loss of energy. Improvement is to be obtained by some method of regeneration. The Central London Railway is a case in point. Mr. Greathead, who was responsible for this line, adopted the switchback principle, and trains are partly braked by going up hill and partly started by running down hill. The result is that in spite of its frequent stations and high average speed it is more than twice as efficient as the Liverpool Overhead Railway. Of the proportion of energy reaching the train I found that nearly 50 per cent was spent in useful work—about 20 per cent in braking, and another 20 per cent in starting resistances. One cannot help feeling that this principle of regeneration for braking and some form of inductive or other electrical variable-ratio method during acceleration contain promise of better results than those shown in the author's curve. I would suggest that renewed attention should be given to this question of saving energy on railways as more likely to yield an immediate practical result than any attempts, however praiseworthy, to get the supply authority to provide energy at such low prices as those which the author suggests. Whilst fully alive to the difficulties of the subject, I cannot help thinking that the curve in Fig. 1 amounts to a condemnation of the present methods of using energy on the urban railways of London. Mr. Mordey

Mr. Sayers. Mr. H. M. Sayers: I wish to emphasize and welcome the fact that the author has stated that the goods traffic and the shunting traffic on railways under present conditions can be economically worked electrically. That is an important fact, which has been known to a number of railway electrical engineers for some years, but I think this is only the second time that I have heard it stated publicly. We may hope to find some practical result from that statement and from the figures which back it up. With reference to fast passenger services, I think we can agree with the author that such services will be the last to be electrified; but I do not admit that the position is quite so hopeless, even under present conditions, as he assumes. He says that an electric locomotive has not been built to maintain its draw-bar pull at 70 miles per hour; but there are probably half a dozen competent motor designers present at this meeting who would be ready to provide him with any number of such motors. For high-speed heavy work the possibility of using the whole of the weight of the load for adhesion is a very great advantage. It is one which steam cannot possibly give, and it is one which, as soon as it is necessary to increase the working capacity of a line beyond the limits of steam, gives electricity the first place and the only place. It should be noted that the author's railway conditions are present conditions. The future effects of electrification are not considered at all in this paper, and are also left out of account by a great many railway authorities. The effect of electrifying a railway in this country is not, as a rule, to reduce working expenses—either the actual working expenses or the total expenses including capital charges. The effect must be to improve the service which the railway can give, and thus to increase the earning capacity. A very large proportion of the capital expenditure on a railway is due to acquiring land, constructing the permanent way, building stations, and providing terminal facilities. The amount of revenue which can be obtained from the track with steam conditions is limited. If a larger revenue is required, such revenue can only be obtained by electrification or by its equivalent. Many railways in this country have incurred heavy expenses for doubling their lines, increasing the station facilities, and improving the gradients, in order to increase their capacity for dealing with the traffic that is offering; but they are adhering to steam working. I venture to say that in most of those cases to-day the extra facility and the extra earning capacity could be provided at a lower total working cost by electrifying the present lines. There is one example in London to-day of the effect of electrification which has been brought to my notice very forcibly. The electrification of the London, Brighton, and South Coast Railway Company's lines between Victoria and the Crystal Palace has been accompanied by a large increase in the service of trains, and that has induced a great increase in the traffic. It is not only "rush-hour" traffic. At any time of the day, between 11 o'clock in the morning and 5 o'clock in the afternoon—the hours which, under steam conditions, were "dead" hours—the trains on the line are full. It seems to me that railway companies have to look in that direction for remuneration for their expenditure on electrical working.

avers. Although it does not perhaps appear to the average person that a very large increase of service on the long distances would pay, I should not be at all surprised if it were found that it does pay and will pay, and that at some not very distant future time it will be possible to go to Euston or St. Pancras for a train to Manchester without consulting the time-table and without having to wait very many minutes.

(*Communicated*): To the author's statements of what steam does, and electric traction must do at least equally well so as to be substituted for steam, it would be well to add some of the things which steam traction fails to do, and which electric traction would evidently facilitate. None of the great English railways gives a reasonably good passenger service to the small towns and villages on its trunk lines. The difficulties in doing so with steam trains, and at the same time keeping clear roads for the fast long-distance traffic, are obvious. The higher acceleration and deceleration associated with electric working are needed for such local trains. The author's views as to working goods traffic electrically suggest that by the same equipment good local passenger services can be made available. Such improvements in frequency and speed of the passenger service will rapidly develop a large amount of additional traffic, or all past experience will be falsified. The author's statements as to the position of suburban railways in competition with road-borne traffic, tramways, and motor omnibuses, cannot be admitted as either complete or well founded. The free use of the highways by pedestrians and passengers generally is a civil right, antedating the railways by many centuries.

Mr. J. M. KENNEDY (*communicated*): There appear to be two reasons for the electrification of suburban railways on which the author has not laid sufficient stress. First, the public are becoming gradually accustomed to faster and more luxurious methods of travel, and those districts which are best served will undoubtedly attract the largest population. We no longer tolerate the style of travelling that was in vogue 20 years ago, and it is a fair assumption that even 10 years hence a still greater degree of comfort will be demanded. This is no doubt due in part to the wave of prosperity which has been passing over the country, and it seems only right that the railway companies should be able to charge increased fares for the better facilities that are provided. Secondly, there is the question of smoke nuisance, both as regards the general cleanliness and health of the towns, but more especially with reference to the peace and comfort of big terminal stations. In connection with the curve in Fig. 1, it would be interesting to know how the schedule speeds between adjacent stations are calculated on different lines. In the case of a line on which the distance between the stations varies considerably, if the schedule speed is calculated to give a fairly constant energy consumption per train-mile on each section, there should be an improvement in the all-over efficiency and load factor. As regards the generation of electricity, one cannot help feeling that the author's argument against a railway company's generating its own electrical energy might equally apply against the use and maintenance of the electrical equipment of the rolling stock; this in itself necessitates an organization quite different from any already possessed by a steam line, except where a railway has an electrical engineer and staff already prepared for the work. In this case, however, one often finds an electrical generating station for station lighting and other purposes. Apart, however, from the organization, there is the more important question of finance. In one or two very exceptional cases it may be found that an outside authority can give a supply of electrical energy as cheaply (or possibly at a lower price) than the railway company can generate it; but in the great majority of cases this seems most unlikely. A load of 15,000 kw. may be required for, say, 50 miles of route, and it must be remembered that in installing its own plant (when its lines are electrified) a railway company would be able to install the latest and most economical type of machinery. Unless the supply authority install exactly similar plant, its generating costs will be higher, and in addition there will be capital charges on the necessary high-tension cables, which might easily cost £80,000 to £100,000 more than in the case of the railway company's own supply. There is also the question of capital charges on the generating plant, which will be higher in the case of an outside supply than for the railway company, owing to the higher rate of interest required. A railway load has not of course a very good load factor, but it is an open question, depending on individual circumstances, whether it will or will not improve materially the load factor of any other undertaking. With generating units of suitable size the plant load factor can, however, be kept at a fairly high figure throughout the day, and this of course has a most important bearing on economical production.

Mr. A. W. E. HARRIS (*communicated*): With reference to the draw-bar pull of steam and electric locomotives, similar curves to those reproduced in Fig. 2 were included

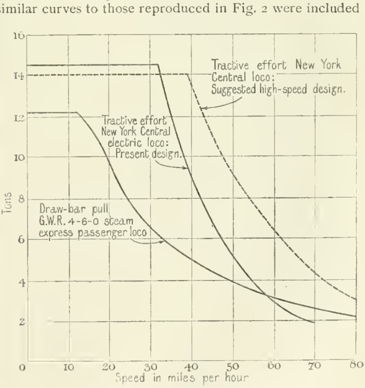


FIG. A.—Curves of Draw-bar Pull and Maximum Tractive Effort at Tread of Wheels.

in the railway electrification discussion at the Paris meeting last year,* but there was then little opportunity of criticizing them. The author uses these curves in support of the assertion that no electric locomotive yet built can give

* *Journal I.E.E.*, vol. 51, p. 611, 1913.

Mr. Harris

results equal to those of the steam locomotive at a speed of, say, 70 miles per hour. Though this is literally true yet by a simple alteration in the design any of the electric locomotives referred to could be made to give a draw-bar pull considerably in excess of the British steam-locomotive pull. This has not been done because in America the tendency has been towards the haulage of heavy passenger trains up to 1,000 tons in weight at moderate speeds, rather than trains of half that weight at higher speeds. The modification of the design necessary to give an increased draw-bar pull would consist in altering the ratio between the speed of the train and the speed of the motors. By increasing the size of the driving wheels, say, the motor would run more slowly for a given speed of the train: but the lower speed would cause the motor to take more current and hence to exert a greater tractive effort. As an illustration of this principle I would refer to Figs. A and B herewith. The full-line curves of Fig. A have

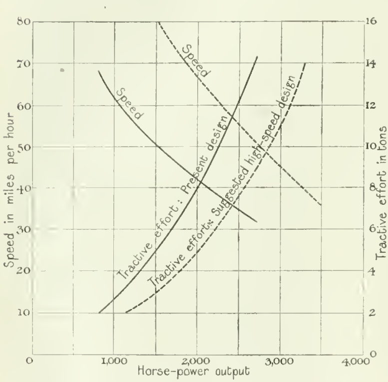


FIG. B.—Curves of Speed and Tractive Effort plotted against Horse-power.

been reproduced from Fig. 2 of the paper for the Great Western steam passenger locomotive and the New York Central electric locomotive. If now the curve of the electric locomotive is plotted in Fig. B with speed and tractive effort as ordinates, and horse-power as abscissæ, the ordinary series-motor curve is obtained, except that the output instead of the input is shown. Suppose, now, the size of the driving wheel were increased by 60 per cent or the motor were re-wound for a proportionately higher speed, the effect would be that for a given horse-power the speed would be increased by 60 per cent and the pull would be reduced by 60 per cent as shown by the dotted curves. But for any given speed both the horse-power and the pull are increased; and if the pull is plotted against the speed in Fig. A again, the curve shown by the dotted line will result. At a speed of 70 miles per hour the new design would give a total tractive effort of 4·33 tons, which should be more than equivalent to the 2·6-ton draw-bar pull of the Great Western Railway locomotive. By further increasing the gear ratio still greater pulls may be obtained at the higher speeds, the only limits being the heating of the motors and the permissible overload at starting. It thus becomes a question of whether the required motor capacity can be installed within the limits of weight imposed by the conditions of the line. In this connection the particulars of the latest electric locomotives being built for the New York Central Railroad may be of interest. These locomotives have been designed for a continuous output of 2,000 h.p. on a total weight of $98\frac{1}{2}$ British tons and with an overload capacity of 4,000 or 5,000 h.p. at starting.* At 75 miles per hour 2,000 h.p. is equivalent to a tractive effort of 4·47 tons, giving a draw-bar pull of say $3\frac{3}{4}$ tons. Mr. Lydall's requirement, which was agreed to by Mr. Roger Smith, was $3\frac{1}{4}$ tons at this speed. The first problem to be faced in competition with the steam locomotive would therefore appear to be capable of solution. Perhaps also the financial problems of main-line electrification, when considered as an addition to already existing suburban electrification, may not appear so insurmountable.

Mr. Woodhouse

MR. W. B. WOODHOUSE (*communicated*): The relationship between the energy consumption per train-mile and the frequency of stopping shown by Fig. 1 of the paper may be emphasized by plotting as ordinates the reciprocals of those chosen, or "stops per mile"; there is then indicated a relationship of the first degree, shown approximately by the equation:—

Watt-hours per ton-mile = 21 + 22 (stops per mile).

For the conditions considered by the author it takes as much energy to start the train from rest as to run it one mile. The author's remarks as to the cost of energy are interesting, but on this point there should be no difficulty in arriving at the price at which energy could be generated by a station used only for traction supply, and therefore at the price at which it will pay to buy electrical energy from a public supply. There is no mystery about the cost of generating electrical energy, and the figure is not difficult to arrive at for any given conditions. In view of the rapid progress that is being made in the economical production of electrical energy by public supply authorities, and the inevitable early obsolescence of present-day generating machinery, one can only regret that so much capital is being spent by railway companies on electric generating plant in preference to purchasing electrical energy from a public supply.

Mr. Smith.

MR. ROGER T. SMITH (*in reply*): It is satisfactory to find Mr. Firth in agreement with what is said in the paper as to the poor return for passenger service. He emphasizes the point for passenger service in general and for suburban service in particular owing primarily to the reduction of fares by competition with other means of transport, and draws especial attention to the fact, appealing at once to the electrical engineer, that the business is a peak-load business. The bulk of the traffic is during a few rush hours morning and evening, so that the transport load factor is as poor as a lighting load factor. With regard to the maximum number of trains per hour that can be run during these rush hours, 44 trains per hour are being run each way on

* *Electric Railway Journal*, vol. 42, p. 1024, 1913.

Smith. the District Railway to-day, and 50 trains per hour has been laid down as a maximum in the Parliamentary Committee rooms. It is not quite certain whether 48 trains have yet been run per hour in an actual service, but there is no doubt that they could be run on lines unhampered by crossings on the level. Flying junctions are essential for such traffic density. The necessity for an electric motor with a variable speed characteristic, even for suburban service, has been very well put by Mr. Firth, who emphasizes the fact that rolling stock cannot be confined to certain definite services. The need for an improvement in an equipment which has only two running speeds was further brought out by Mr. Mordey on the grounds of higher efficiency in the transformation of electrical to mechanical energy on the train. It is to be hoped that this will receive the serious attention of designers. Mr. Firth also points out that it is not right to say that the terminal accommodation is doubled by halving the locomotive and signal movements. This statement is based on the fact that every time a locomotive train comes in and goes out there are four platform operations and eight signal operations. Every time a multiple-unit train goes in and comes out there are two platform operations and four signal operations. In that case accommodation is doubled unless external obstructions interfere.

It is satisfactory to have Mr. Firth's agreement with the argument that on engineering and economic grounds the advantages of electric traction for fast passenger traffic have not yet been shown. With regard to goods working, he also points out that the argument for electric working on the economic side largely depends on whether the increased train mileage worked by the electric as compared with the steam locomotive is possible. This is a most important point and must always be worked out for every particular case. But on the engineering side it must also be remembered that there are cases of mineral and heavy goods traffic in hilly districts where the average speed with steam is only 5 or 6 miles per hour. Even if circumstances did not allow of a reduction in the number of locomotives, an increase of the average speed to 12 or 15 miles per hour might alone justify electrification.

In dealing with the paper Mr. Sparks has not always kept to the distinction there made between urban and suburban and other types of service. The author is not only in agreement with Mr. Sparks that for urban service there is no question of the superiority of electric traction, but says so on page 294. Mr. Shaw's paper on "The Mersey Railway under Steam and under Electric Traction"* gives quantative and economic results, and although no paper has been read collecting the comparison between the steam and electric services on such parts on the London Underground Railway services as were formerly worked by steam, there is no doubt that in both these cases steam had come to the end of its tether. The only drawback is the lowness of the fares. The results of suburban working are not so indisputably successful. It is quite agreed that to recover traffic lost to tramways and omnibuses the only thing for a suburban railway system to do is to electrify, but the economic result may be far from satisfactory to the railway. Mr. Sparks is quite right in pointing out a mistake in the figure given for the reduction in working costs on page 296. Halving the cost of electricity reduces the total cost by 15 per cent and not by 25 per cent. Mr. Sparks's criticism of the sparseness of the service assumed for fast passenger service is welcomed, but it really confirms the argument. A railway having not less than 2,000 miles of route had been purposely assumed. If the other figures assumed are correct, the railway would lose money heavily by electrification. The Brighton Railway is a particular case in which the traffic is far more dense than in the illustration, the figure being about 15,000 train-miles per mile of route averaged over the whole line. The figures given by Mr. Sparks show the effect of density in the problem in the increased money available for electrical equipment of the line per mile of route. Incidentally it suggests that the form of analysis used by the author has some convenience in showing the limiting density of service which would not result in a loss. It is to be remembered that if the figures given in the paper for the annual cost of a locomotive, the train mileage it runs, the cost of locomotive coal and the cost of electricity, are accepted, there would be a dead loss in changing from steam to electric working with a traffic density of only 10,000,000 passenger train-miles per 1,000 miles of route. Mr. Smith.

Mr. Sparks referred to the saving in locomotive coal haulage. Usually haulage for railway purposes is balanced as between one department and another, but haulage of the coal used in a generating station must not be lost sight of. If the railway generates electrical energy, or if electrical energy is purchased, coal haulage equally appears in the bill; but it is convenient to allow for this in the extra train mileage run by the electric locomotive rather than in the annual cost of a locomotive. Mr. Kahler's figures, quoted by Mr. Sparks, for the reduction in train mileage were for a particular case in the mountain ranges of Western America. They would not apply to British conditions. Similarly the locomotive mileage quoted by Mr. Sparks from Mr. Kahler's paper is not an average but a particular hypothetical case, and is not applicable to the argument for British practice. It is quite safe to say that on the average the electric locomotive ought to be able to haul 50 per cent more train-miles than the steam locomotive, but in any individual division or even on a whole railway, as pointed out by Mr. Firth, this may not be possible. A very good example is the main line of the Metropolitan Railway which is electrified as far as Harrow and is used for steam traction from there to Verney. In this case the annual mileage run by steam engines is about double the mileage run by electric engines. This ratio will be altered when the extension of the electrification contemplated by the Metropolitan Railway is complete. At present the electric service is of the nature of a rather extended terminal service which, as pointed out by Mr. Sparks, must give a poor mileage per locomotive.

Mr. Sparks criticizes the figure of $7\frac{1}{2}$d. per train-mile on 40,000 train-miles. He forgets again that the paper deals with average conditions over 2,000 miles of route, including small locomotives for local and branch traffic. This figure is based on an average of 200 tons for the train, including locomotive, and 50 watt-hours per ton-mile. The Pennsylvania trains weigh 1,000 tons. In any case the figures in the paper show that for fast passenger service the case for electricity is hopeless; but I believe

* *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 179, p. 19, 1909–10.

Mr. Smith. the annual cost of £1,250 per electric locomotive to be correct on the average for all sorts of service over 2,000 miles of route.

Dr. S. P. Smith supplied several conditions governing electrification which the paper omitted. It only claimed to refer to some of them, and others were specifically left out because they were to have been dealt with in one or other of the following papers. With regard to the reasons for electrification, Mr. Aspinal has stated that his railway electrified not to save money but to make more. It is the only managerial pronouncement of which the author is aware, and it puts the case admirably.

Dr. Smith rightly calls attention to the importance of the independent unit in the shape of the steam locomotive. If all lines had been electrified and the steam locomotive were then invented, it is conceivable that as a new thing it might be hailed as an immense convenience and improvement. Dr. Smith reconstructed the single-phase locomotive in use for the Lötschberg Tunnel and showed that it could run at 70 miles per hour. No doubt the motors could be designed to give 1,100 h.p. at between 70 and 80 miles per hour, but the speaker did not then say what starting pull it would give. The steam locomotive is a constant-output machine. No electric locomotive yet made is a constant-output machine, but Dr. Smith seemed to assume that it was, and without his diagram to refer to it does not necessarily follow that the locomotive will give its rated horse-power of 1,250 at any speed. The paper does not say—and this equally refers to a criticism by Mr. Sayers—that an electric locomotive suiting British limitations of drawgear cannot be made to give the same pull at maximum speed as a fast passenger steam locomotive; but that such a locomotive has never yet been made, and until it has been made and run successfully we cannot discuss it.

Professor Dalby's diagrams of overall efficiency between the heat in the coal and the work done agree fairly well with the figures given in the paper on page 299, namely 3¼ per cent for the steam locomotive and 6 per cent for the electric locomotive.

Mr. Mordey's criticism was very much to the point. He showed that for suburban service an improvement in the use of the energy, by reduction or elimination of the losses, was wanted rather than a decrease in the cost of electrical energy and in the first cost of the locomotive. It is useful to remember that 1 lb.-per-ton train resistance is equal to 2 watt-hours per ton-mile at 100 per cent efficiency, so that for the service considered on page 300 and in Fig. 1, where the measured train resistance averages 16 lb. per ton, the number of watt-hours per ton-mile at 100 per cent efficiency to overcome resistances only is 32. This allows nothing for imparting momentum which is afterwards destroyed, but although the efficiency is not quite so bad as that given by Mr. Mordey, who assumed 10 lb.-per-ton train resistance, it is bad enough. The improvement must come from the designer, and it is probable that the railway engineer has not worked with him sufficiently. It is satisfactory that Mr. Mordey has drawn special attention to this point and especially to the question of regeneration. Mechanical regeneration, as on the Central London Railway, is perfect where obtainable and for trains that stop at every station. Electrical regeneration so far seems only to be completely under control with three-phase motors. All accounts that have been published of single-phase and continuous-current regeneration seem to show that the voltage is so little under control that it is more trouble than it is worth. It needs careful consideration not only for mountain railways but for suburban working, and if obtainable under complete control it would be of great importance.

Mr. Mordey asked for the proportion of the total capital cost of the electrification that must be allocated to the locomotives. Each individual case is different, and it was because of this difficulty that the form of analysis used in the paper was put forward. In this the locomotive annual capital, working, and renewal costs are averaged over the whole line. Granted certain assumptions as to the cost of locomotive coal, the cost of electrical energy, and the resulting train mileage, any difference in favour of the electric locomotive is available for the electrical equipment of the line, when capitalized, and for profit. Of the annual costs, capital charges at 6 per cent for the locomotive form 13 per cent in the case of the steam and 18 per cent in the case of the electric locomotive. If the cost of the electric locomotive is halved the capital charges drop to 12 per cent of the annual costs.

Mr. Sayers gave excellent engineering reasons for the electrification of passenger services, pointing out that the conditions taken by the author were present conditions. It is important for electrical engineers to realize that steam locomotive engineers are not standing still. At Mr. Fowler's paper on the superheating of steam locomotives which was read and discussed for three nights last month before the Institution of Civil Engineers, the superheating of locomotives was described as the greatest advance that had been made within recent years. The curves for steam locomotives given in Fig. 2 are for saturated steam. They would be considerably better for superheated steam, and especially is that the case at high speeds. Mr. Sayers's remarks all point to the fact that electrification of railways comes in when steam has reached the end of its tether. With that statement the author is in hearty agreement, the point being to decide when steam has come to the end of its tether. There is no question about underground working or dense urban and suburban working, but it is a great mistake to suppose that steam locomotive improvement is at a standstill. The increase in the Brighton traffic due to electrification is referred to on page 295.

Mr. Sayers's communicated remarks as to improvement in the services for branch lines by electric working suggest the system which it is believed will be used on the suburban system of the French State Railways. On its electrified sections every coach is to be a motor coach, seating 100 passengers and with standing room for 100 more. Coaches can run coupled as trains, driven by multiple-unit control, and be shed singly at junctions for branch traffic, joining the train again for the return main-line journey. Such traffic working can only be done electrically. Mr. Sayers no doubt thinks it just that for 25 municipal tramway concerns which in 1912 received support from the rates, the larger part of that support should come from the railways with which they compete, but which are not represented municipally. The moral is: "Happy is the railway without an urban and suburban service."

Smith. It is refreshing to find a member of the travelling public, if I may so call Mr. J. M. Kennedy, acknowledging the justice of the argument that the demand for faster, more frequent, and more luxurious railway service entitles the railway to higher fares. Were it possible for that view not only to be acknowledged but acted upon, the present difficulties of the railway companies in improving their suburban services by electrification would cease. At present the handicap in favour of the railway's competitors stated on pages 295 and 296 of the paper, as well as statutory obligations as to fares, stand in the way. If only suburban traffic could be made to pay, instead of being, as is often the case, a burden on the long-distance and goods traffic, it would be possible for all the railways to give the public increased facilities for living at distances up to 30 miles away from their work. Mr. Kennedy combats the view that it is better for the railway to buy electrical energy than to generate it. The railway can only invite offers to supply, and if none of them is worth accepting it must generate electrical energy for itself. Mr. Kennedy suggests that it is easier for the railway than for the supply authority to buy so-called up-to-date machinery; but is it easier for the railway to scrap obsolete machinery? The principles on which most railways work with regard to their machinery, in accordance with the system of accounting imposed on them by the Board of Trade, is to maintain and renew out of revenue. If any money is put aside for obsolescence the amount is small and will only reproduce the capital in a long period of years, as it is against the spirit and practice of railway accounting to provide for rapid obsolescence. Experience has shown how necessary it may be to scrap electric generating plant after a short life, but the imposed form of railway accounts makes no provision for this except as a lump sum out of revenue for that particular year, and the temptation to a railway company to allow plant to become obsolete is considerable. In addition to this, electrification costs so much, and capital is wanted for so many other purposes, that the saving of the money necessary for the land, buildings, and machinery for generating electrical energy may make all the difference to the acceptability of a scheme. When the power required is Mr Smith. well under 20,000 kw. the cost to the railway of a complete power station should in general be greater than the cost to a supply authority of increasing its existing plant. London with its multiplicity of small stations is at present as bad a place as can be found for buying electrical energy for railway purposes. As to the view that the maintenance of electric equipment on rolling stock is equally a new business to the railway as electric supply, the railway must maintain its electric equipment whether its wants to or not, while it need not supply electricity if it can buy it on favourable terms. It is not to be lost sight of that there is much more chance with a diversity of supply for prices to become more favourable with time if electrical energy is bought, than if it is generated by a railway company in a power station that is debarred from selling energy to anybody else other than a railway, and may have no chance of increasing its output.

Mr. Harris has reconstructed the characteristic curves of the New York Central electric locomotive shown in Fig. 2 (which is not the latest design) to run at over 70 miles per hour. This he does by installing larger motors and gearing them up by increasing the diameter of the driving wheels. This gives appreciably more than the horse-power output and draw-bar pull of the 2—6—0 steam locomotive at 70 miles per hour. Between 10 and 20 miles per hour the steam locomotive only needs to develop some 1,250 h.p. The geared-up electric locomotive can apparently develop more than 4,000 h.p.; and as a continuous-current equipped machine the waste in rheostatic control would more than justify Mr. Mordey's strictures on the inefficiency of electric traction. Something better than the installation of more than 4,000 h.p. to develop 1,200 h.p. seems needed before it can be said that a continuous-current locomotive has been designed capable of competing with the modern high-speed steam locomotive.

Mr. Woodhouse very neatly shows the meaning of the curve in Fig. 1 by plotting the number of watt-hours with stops per mile, and his equation has far more meaning than if the curve itself be expressed as a logarithmic equation.

Birmingham Local Section, 11th February, 1914.

Taylor. Mr. A. M. Taylor: The curves in Fig. 2 of the paper are very instructive, and quite emphasize the point which the author has put forward, namely, that at the high speeds suitable for fast passenger traffic, electric locomotives as hitherto constructed have been deficient in draw-bar pull as compared with steam locomotives. I understand that this is still more the case if they are compared with the latest forms of superheated steam locomotives. The two types which are selected for comparison in Fig. 2, viz. the 2—8—0 Great Western steam goods locomotive and the 4—6—0 Great Western steam passenger locomotive, illustrate the different performances of the steam locomotive very well. It will be noticed that while the curve representing the performance of the former falls rapidly after a speed of about 27 miles per hour has been reached (that is to say the draw-bar pull falls off rapidly with an increase of speed), yet on the other hand the curve representing the performance of the latter maintains a high value for the tractive effort right up to a speed of 50 miles per hour, Mr Taylor. only diminishing slowly after that point. In fact, the curve lies very nearly upon the constant-horse-power curve for 1,000 h.p. But the two Pennsylvania electric locomotives give a draw-bar pull which decreases very rapidly when the speed exceeds 40 miles per hour, and the curve passes across the constant-horse-power curves, as also does the curve of the New York Central electric locomotive. The curve of the New York, Newhaven, and Hartford electric locomotive, on the other hand, shows a somewhat better performance. It is, of course, well known that the continuous-current series motor, although it has excellent characteristics as regards the initial stages of acceleration which render it highly suitable for local suburban lines, falls off considerably in its pull as it reaches a steady running speed corresponding to that in which all the resistance is taken out. Series-parallel control, if it were workable, would give improved results, but between the

Mr. Taylor. two final speeds there would be a large gap over which efficient running could not be maintained. Some means is needed for meeting this condition. The author has pointed out that a single-phase locomotive can partly be adapted to these conditions by absorbing voltage in reactances at the lower speeds. What, therefore, is wanted appears to be an electric locomotive which for a given expenditure in copper and iron will give a very large draw-bar pull at high speeds. This may be obtained apparently at the expense of diminished acceleration at the low speeds, although on the other hand there is a large margin of draw-bar pull available at the lower speeds for acceleration on account of the fact that the pull increases as the 5/3rd power of the speed. I cannot believe that it is outside the capacity of electric railway engineers, when once they know the conditions that have to be met, to design a locomotive suitable for high-speed passenger service, and I feel confident that now Mr. Roger Smith has propounded the conditions it will not be long before designers are able to comply with these. On the other hand, I understand that the author considers the capital outlay and the cost of working to be no less than with steam for this particular class of service, and therefore to offer no great inducement to the introduction of electric traction. As regards the cost of the locomotive itself, I think this depends largely upon the standardization of designs and the building of a considerable number of locomotives. The initial cost, however, must necessarily be very heavy. As regards the cost of running, the author hints that the railway companies do not care to undertake such a big experiment as the generation of electrical energy for railway work on a large scale, which they feel would require a large staff for its introduction and operation, and might be better undertaken by those who have been accustomed to supplying electrical energy on a large scale. Here, again, I cannot help thinking that if it is once known that this is the attitude of the railway companies, the large suppliers of electric power will not hold back; but of course the railway companies must not expect them to undertake the supply of energy at prices which are unremunerative in order merely to introduce electric traction. The author mentions getting current at ¼d. per unit. I do not think there is any probability of his obtaining that happy result at present, and I do not think the railway company at any rate could generate energy at that figure or even near it. It would be interesting to know something more about the designs of the locomotives which gave the draw-bar pulls shown in the curves in Fig. 2, and whether any of them were other than continuous-current locomotives. Mr. Taylor.

The author has apparently made out a good case for the electric goods locomotive, and I can see no reason why, if this be so, electrical engineers should not concentrate their energies on introducing electric locomotives for this class of work. It would appear to be the "thin end of the wedge" for long-distance work and would probably bear the cost of the electrification of the line, which need not then be debited to the high-speed passenger service when electric locomotives for this were introduced later. In conclusion, I feel sure that this paper will serve good purpose in laying before electrical engineers the reasons for the slow progress hitherto made in railway electrification and the lines on which future developments should be shaped.

Mr. R. T. Smith (*in reply*): Mr. Taylor emphasizes the fact, clearly shown in Fig. 2, that for the high speeds required in fast passenger service the steam locomotive—which is a constant-output machine over almost its whole range of speed—seems to meet the case, while the series-motor electric locomotive is so far from being a constant-output machine that at high speeds its power falls off very rapidly. It must not be forgotten that even for high-speed services spare power at low speeds for acceleration is most useful, enabling the maximum speed to be lowered, and providing for hauling up grades at increased speed. Mr. Smith.

We do not want to turn the electric locomotive, even for fast passenger service, into a constant-output machine, as the greater the power available at starting, over and above that required to overcome resistances, the sooner will the train reach average speed. What is wanted, however, is a design in which the falling off of power with speed is not so marked as it is at present with motors having a series characteristic.

For goods service and for suburban services the limitations of speed are for the most part within the limitations of the series characteristic, but the want of flexibility of a one-speed motor for any one load is a very serious drawback as compared with the steam locomotive. It is satisfactory that Mr. Taylor should have drawn special attention to that part of the problem.

ANNUAL DINNER, 1914.

The Annual Dinner of the Institution was held in the Grand Hall of the Hotel Cecil on Thursday, 5th February, 1914. The President, Mr. W. Duddell, F.R.S., presided over a gathering numbering about 390 persons. Among those present were: The Hon. Sir C. A. Parsons, K.C.B., F.R.S. (*Honorary Member*), Sir Thomas Barlow, Bart., K.C.V.O. (*President of the Royal College of Physicians*), Sir George R. Askwith, K.C.B. (*Chief Industrial Commissioner*), Sir H. F. Donaldson, K.C.B. (*President of the Institution of Mechanical Engineers*), Sir W. Graham Greene, K.C.B. (*Permanent Secretary to the Admiralty*), Sir John Bradford, K.C.M.G. (*Secretary to the Royal Society*), Colonel Sir T. H. Holdich, K.C.M.G. (*Chairman of the Roya' Society of Arts*), Sir John Gavey, C.B. (*Past President*), Sir J. Crichton-Browne, LL.D., F.R.S. (*Treasurer to the Royal Institution*), Sir Alfred Kempe, F.R.S., D.C.L. (*Treasurer to the Royal Society*), Sir J. McClure, LL.D., Sir H. Trueman Wood, M.A. (*Secretary to the Royal Society of Arts*), Major-General S. B. Von Donop, C.B. (*Master General of Ordnance, War Office*), Dr. R. T. Glazebrook, C.B., F.R.S. (*Past President*), Mr. W. F Marwood, C.B. (*Assistant Secretary to the Railways Department, Board of Trade*), Dr. F. G. Ogilvie, C.B. (*Adviser to the Science Department, Board of Education*), Mr. A. M. J. Ogilvie, C.B. (*Member of Council*), Mr. F. Pullinger, C.B., Rear-Admiral E. F. B. Charlton (*Assistant Director of Torpedoes*), Colonel G. M. W. MacDonogh

(*General Staff Officer, Imperial General Staff*), Lieut.-Colonel P. G. Von Donop, R.E. (*Chief Inspector of Railways, Board of Trade*), Captain E. O. Henrici, R.E. (*Member of Council*), Mr. A. B. Anderson (*Member of Council*), Mr. F. E. Berry (*Member of Council*), Mr. R. A. Chattock (*President of the Incorporated Municipal Electrical Association*), Mr. E. Russell Clarke (*Member of Council*), Mr. E. G. Dawber (*Vice-President of the Royal Institute of British Architects*), Dr. S. Z. de Ferranti (*Past President*), Mr. F. Gill (*Member of Council*), Mr. R. Hammond (*Hon. Treasurer*), Mr. W. Hartnell (*Past Chairman of the Yorkshire Local Section*), Mr. J. S. Highfield (*Member of Council*), Mr. H. Hirst (*Member of Council*), Mr. G. W. Humphreys (*Chief Engineer to the London County Council*), Mr. W. Judd (*Vice-President*), Mr. J. E. Kingsbury (*Member of Council*), Professor T. Mather, F.R.S., Mr. W. M. Mordey (*Past President*), Mr. H. A. Payne (*Comptroller of Companies Department, Board of Trade*), Professor A. W. Porter, F.R.S. (*President of the Röntgen Society*), Mr. Garnham Roper (*Assistant Secretary to the Harbour Department, Board of Trade*), Dr. A. Russell (*Member of Council*), Mr. W. Rutherford (*Member of Council*), Mr. A. H. Seabrook (*Member of Council*), Dr. W. N. Shaw, F.R.S. (*Director of the Meteorological Office*), Mr. A. Siemens (*Secretary to the Royal Institution, and Past President I.E.E.*), Mr. R. T. Smith (*Member of Council*), Mr. J. F. C. Snell (*Vice-President*), Mr. J. Swinburne, F.R.S. (*Past President*), Mr. A. M. Taylor (*Chairman of the Birmingham Local Section*), Professor S. P. Thompson, F.R.S. (*Past President*), Mr. H. E. Wimperis, M.A. (*Member of Council*), and Mr. P. F. Rowell (*Secretary*).

The PRESIDENT gave the toasts of "His Majesty the King," and of "Her Majesty the Queen, Queen Alexandra, His Royal Highness the Prince of Wales, and other Members of the Royal Family."

SIR JAMES CRICHTON-BROWNE, LL.D., F.R.S. (Treasurer to the Royal Institution), in proposing the toast of "The Institution of Electrical Engineers," said : In the regrettable absence of Lord Moulton, regretted by no one more than by me, I am suddenly called upon to propose this important toast. But as a medical man I am gratified to have this duty assigned to me, for medical men feel a constant pride in the advance of electricity. It was a medical man, Dr. William Gilbert, who gave us the word "electricity" and laid down the foundations of electric and magnetic science on sound experimental and inductive lines. Galvani, the inventor of the metallic arc, whose observations led to Volta's epoch-making discovery, was a medical man. Sir Thomas Young, who first affirmed the identity of electricity and galvanism, was a medical man. Meyer, who first propounded not only the mechanical theory of heat, but the doctrine of the conservation of energy which lies at the basis of so much electrical work, was a medical man. Helmholtz, who stimulated Hertz to those researches that led up to wireless telegraphy, was a medical man. Besides these great and shining stars in the electrical firmament I could mention others of minor, but still of considerable, magnitude of medical affinities, but that I fear it would be thought I was going to appropriate all the merits of the electrical engineers to my own profession. Medical men have recognized that there is a curative value in electricity, and have freely availed themselves of it in those engineering operations which they have to perform on the human body in cases of paralysis and other diseases. Not merely as a medical man but as a representative of the Royal Institution of Great Britain I am gratified in having to propose this toast, for it was in the laboratory of the Royal Institution that there was planted that mustard seed of electricity which has grown and become the greatest of herbs and a tree in which is lodged this immense flock of birds of sombre plumage but of cheerful song whom I see assembled here this evening. It was in the laboratory of the Royal Institution, if I recollect rightly on the 29th August, 1831, that Faraday performed an experiment with an iron ring and a bit of copper wire which was the foundation of the electrical studies that led to the electro-magnetic and dynamo-electric machines. Electrical engineers perhaps hardly realize how far their influence reaches. I can assure them I have found it in every lunatic asylum in the country, not as electric lighting but as mental observations. The commonest forms of insane delusions in these days are connected with electricity. Thousands of unhappy beings have their night's rest constantly broken by electric shocks ; thousands are constantly receiving wireless messages of an insulting and objectionable character. Thousands have their brains kept in an incandescent state by confounded electrical apparatus of one kind and another. I do not know whether we shall shortly have in our lunatic asylums those etheric impressions which have been recently discussed in *The Times*, and which have been thought to be a proper explanation of spooks and ghosts of all kinds. But at any rate at this moment it is electricity that holds the field. I recall one interesting experiment performed by Faraday. He was able to produce gold leaves of such thinness that it would take thousands of them to make the thickness of an ordinary sheet of notepaper ; and these leaves were transparent and of a dull green colour. It occurs to me that while all electrical engineers may admire Faraday in his electrical relations, they do not follow him in his experiments upon those gold leaves. The gold that passes through their hands is much thicker, and there is no green about it. I hope there is plenty of it, and that boundless wealth is in store for all the members of this distinguished Institution, whose health I am proposing. It is a great pleasure to propose the toast of an Institution which has shown such remarkable growth, and which is of such immense public utility. I have to couple with this toast the name of the President, Mr. Duddell, who looks so young and is so wise. I will not pass any judgment upon his electrical labours, but this I will say from my own knowledge, that he has the power of clear and of brilliant exposition, and that his experiments never fail. I have the pleasure of proposing the toast of "The Institution of Electrical Engineers," coupled with the name of the President, Mr. Duddell.

The PRESIDENT (Mr. W. Duddell) in responding to the toast said : I am rather at a loss to know what to say, but in the first place I must thank Sir James for the exceedingly kind way in which he has proposed this toast, and those present for the hearty manner in which they have received it. The toast is a double-barrelled one ; it couples the Institution of Electrical Engineers with my name. In proposing the toast Sir James has referred to those medical men who have helped electrical engineers and who were

in fact the pioneers of electrical science. He has also made such a complimentary speech that I hardly know how to reply. There is one thing, however, that I must say. I have recently been suggesting to the Institution that we ought to extend our fields of usefulness, and that we ought to take up all kinds of new developments. Another field has now been suggested: that the Institution of Electrical Engineers should try and help the medical profession in applying electricity to the amelioration of the ills of the human race. I thank Sir James for making this suggestion, and I hope we may be able to act upon it.

This is the second Annual Dinner at which I have had the honour of presiding; I therefore do not think I need say very much about the work of the Institution. The proposer of the toast is, as we all know, the Treasurer of the Royal Institution, and he has referred to the work that Faraday did there. I think there is no other Institution in this country which recognizes so well as we do our indebtedness to that great man, Faraday, for laying the foundations of our science. But I do not think our indebtedness to the Royal Institution ends there. Year by year valuable work is carried out in its laboratories; nearly every new invention is described in its Lectures, and we have the privilege of hearing what is going on in that most valuable Institution, which dates back a whole century or more. As the representative of one of the younger societies I should like to express our indebtedness to the Royal Institution for the valuable work which it carries out. Sir James has suggested that electrical engineers are on the point of receiving a large amount of thick gold. I only hope it may be true. I will conclude by again thanking, on my own behalf and on behalf of the Institution, Sir James and those present for the hearty way in which this toast has been received.

Dr. S. Z. de Ferranti then proposed the toast of "Our Guests," to which Sir George Askwith, K.C.B., K.C., responded.

A re-union was subsequently held in the Victoria Hall of the Hotel.

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ELECTRIC LOCOMOTIVES.

(SUPPLEMENTARY PAPER.)

By F. LYDALL, Member.

(*Paper first received 29th January, and in final form 16th February, 1914.*)

Since the author's paper on "Electric Locomotives" published in No. 222, Volume 51, of the *Journal* was completed, a few new designs have been developed and a certain amount of fresh experience has been gained. It may be of interest to bring forward these new designs with a brief reference to each, in order to complete the list, and also state, so far as is possible under the circumstances, the present position in regard to locomotive design in general. It will of course be understood that information as to the results obtained with locomotives of different kinds is not readily available, such experience being frequently acquired at great expense, and therefore being usually regarded as confidential. Messrs. Siemens Schuckert of Berlin have, however, been good enough to place at the author's disposal some hitherto unpublished information with regard to the working of one of their latest types of locomotive, from which certain general conclusions can be drawn. This is referred to below.

NEW DESIGNS.

Four new designs are illustrated in Figs. 1 to 4, two having been brought out by the Bergmann Elektricitätswerke Aktien-Gesellschaft for the Silesian Railways, one by the Maschinenfabrik Oerlikon for the Lötschberg Tunnel Railway, and one by the General Electric Company of America for the New York Central Railroad. Particulars of the motors with which these locomotives are equipped are given in the author's paper on "Motor and Control Equipments for Electric Locomotives."*

1. *Type* 2—D—1 *by the Bergmann Elektricitätswerke A.G.*—The general arrangement is shown in Fig. 1, the special feature being the provision of two jack shafts coupled by inclined connecting rods to the armature shaft of the single motor. The obvious advantage of this design is that the torque produced by the one powerful motor is divided between two jack shafts. The locomotive is at present in course of construction.

2. *Type* 2—B+B—1 *by the Bergmann Elektricitätswerke A.G.*—The general arrangement is shown in Fig. 2. The rating of the two motors on this articulated locomotive is the same as that of the single motor in the foregoing 2—D—1; the mechanical arrangement is, however, entirely different, the jack shaft in each half being geared to the corresponding motor shaft. This locomotive is also at present in course of construction.

Messrs. Siemens Schuckert are also building a locomotive with gear-wheel drive on to jack shafts for the Silesian Railways.

3. *Type* 1—E—1 *by the Maschinenfabrik Oerlikon.*—The general arrangement is shown in Fig. 3; the two motors are geared to two jack shafts which drive on to the middle of the five driving axles by Scotch jokes. This locomotive has already been running for some time on the Lötschberg Tunnel Railway.

4. *Type* B+B+B+B *by the General Electric Company of America.*—The general arrangement, as shown in Fig. 4, consists of four articulated trucks each equipped with two bipolar motors of similar construction to, but smaller in size than, those on the original New York Central locomotives. The trucks are grouped together in pairs by two frames, these frames carrying the body.

The first of these locomotives was delivered for experimental running about 18 months ago, as a result of which further locomotives of the same design were ordered. The duty for which they have been designed is to haul trains of 900 tons (American) at express speeds, that is, up to about 60 miles per hour; but Mr. Katte has informed the author that the motor armatures are to be enlarged to enable trains of 1,100 tons (American) to be hauled. Mr. Katte also states that the riding qualities of the locomotive are excellent.

* See p. 384.

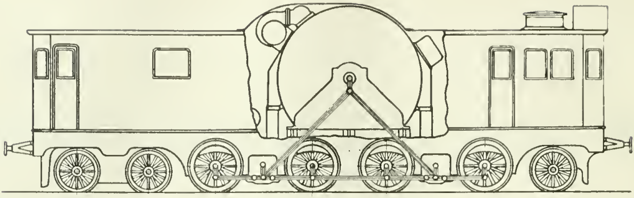

Fig. 1.

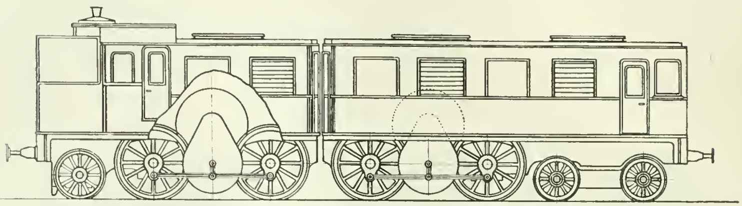

Fig. 2.

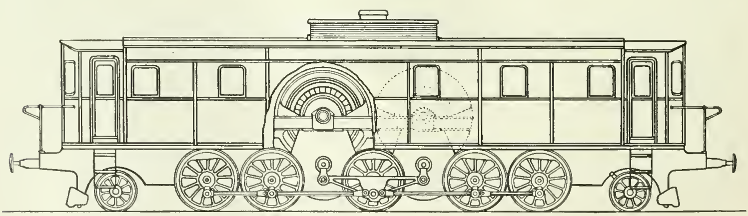

Fig. 3.

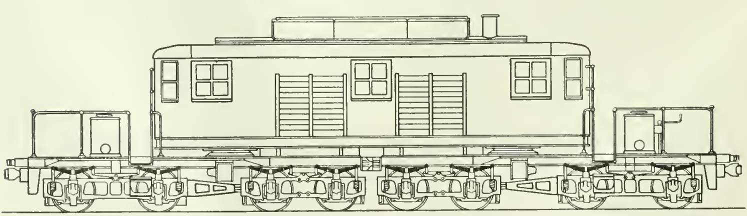

Fig. 4.

Before leaving the subject of new designs, mention must be made of the so-called "two-rod drive" developed by Messrs. Brown Boveri. Two locomotives of the general type 1—C—1 have been ordered from this firm by the Baden State Railway Administration for service on the Wiesenthal line. Up to the end of last year only one had been delivered.

The special feature of this design is that the two motors which are mounted near the centre of the body and well above the centres of the driving axles drive direct on to the central driving axle without the intermediary of any jack shaft. The arrangement follows the lines of the Scotch yoke system in that the bearing on the crank-pin of the driving axle is free to move up or down in a vertical slot in the connecting rod which connects this crank with the corresponding crank of one of the motors. It differs, however, from the Scotch yoke in that the two connecting rods from the cranks of the two motors are pivoted together at the bottom angle instead of being rigidly connected so as to form a frame. The general arrangement is shown in Fig. 5.

The object of this design is to eliminate the heavy and expensive jack shafts with their cranks and bearings, etc., and at the same time to provide an arrangement in which great accuracy of adjustment (of motor axle and jack shaft positions) is unnecessary. It is too soon to say definitely whether this design is successful in practice or not, as from one cause or another the locomotive has so far seen little service.

Turning now to the general experience with electric locomotives of various designs, it appears to be fairly well established that for railways equipped on the continuous-current system, either high-tension or low-tension, shunting locomotives and those intended for hauling heavy goods and mineral trains at the speeds customary in this country are best made on the articulated bogie principle with four geared motors suspended on the bogies in the ordinary way.

For railways on which the electrical supply is on the three-phase or single-phase alternating-current system, the choice of drive is perhaps rather more open. There is a tendency towards concentrating the motive power in one or two motors, and these must necessarily be connected to the driving axles by connecting rods on one system or another, so as to utilize the total weight of the locomotive for purposes of adhesion. This introduces at once the consideration of coupling-rod drive in the light of recent experience.

Attention has been drawn in the technical press on one or two occasions during the last six months to the difficulties experienced on the Wiesenthal Railway with the locomotives supplied by Messrs. Siemens Schuckert. These locomotives are of the 1—C—1 type with two single-phase motors driving down by connecting rods on to a single jack shaft between two of the three coupled driving axles. Nine of these locomotives were delivered during last year, and during the first month of working a number of mishaps occurred, some trifling and others more serious. The occurrences of minor importance were due to difficulties with the four-part motor bearings, troubles with the sand pipes, and other small details. These matters were attended to and put right without any serious disturbance or any substantial modifications of the general design. Such small difficulties are to be expected whenever locomotives of a new type and with new equipments are first put into operation.

The more serious mishaps were not to be explained in the same way, and were apparently due to some fundamental cause. After a great deal of observation it was found that at a certain speed the connecting rods and coupling rods on both sides of any of these locomotives started to vibrate, and that this vibration gradually increased as the speed rose, until at a speed of about 36 kilometres per hour it reached a maximum of considerable amplitude. At this speed there seemed to be the equivalent of resonance, as the vibration practically disappeared as soon as the speed had risen to 40 kilometres per hour.

It is of special interest to remark that this peculiar performance of coupling-rod systems is observable on

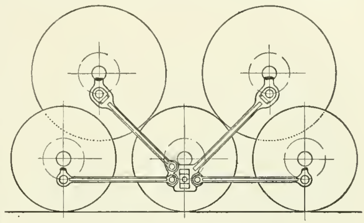

FIG. 5.—Brown Boveri 2-rod drive.

practically all locomotives in which the effort of the motor or motors is transmitted to the driving axles by means of connecting rods. It is especially noticeable in those cases in which a pair of motors is coupled to a single jack shaft, or are rigidly coupled together by any arrangement of connecting rods, and is not confined to the construction adopted for the Wiesenthal locomotives, but is also observable with Scotch yokes, as on the 1—E—1 locomotive for the Lötschberg Tunnel Railway, on which breakages of the yokes have taken place. The same experience, although to a less extent, is found on locomotives in which each motor, if there are more than one, drives on to a single jack shaft, such as the 1—C—1 for the Prussian State Railways. The same effect has also been observed on the 2—B+B—2 locomotives of the Pennsylvania Railroad, although in this case the vibration is very slight.

Having recognized this as the fundamental cause of the breakages referred to above, Messrs. Siemens Schuckert devised a new arrangement—particulars of which the author is not at liberty to publish—which, so far as can be seen after several months' working, eliminates the trouble. The new arrangement does not require any far-reaching alteration to the general design, the jack shaft being used as before with the two connecting rods and the coupling rods on each side. The alterations have been already carried out on all the nine locomotives. It should be mentioned, however, that the new design is not that of the two-rod system alluded to above and shown diagram-

matically in Fig. 5. The statements that have recently appeared in the technical press to this effect are incorrect.

The experience mentioned above may with advantage be taken into account in considering the most suitable design of locomotive for a given class of service. Partly for this reason, and also on other grounds connected with the first cost, there is a tendency at present on the Continent towards the use of gearing rather than connecting rods for transmitting the torque to the jack shaft or direct to the driving axles. If the author is not mistaken, this is also the general conclusion in the United States, where the connecting-rod drive does not find much favour.

For express passenger service, however, there still remains the difficulty of excessive gear velocity if gear drive is employed. For speeds which would be required in this country, say, 75 miles per hour, it would hardly be practicable to run without some kind of forced lubrication for the gears, as, for example, by jets of oil directed against the surfaces of the gears in contact. It may be, however, that a locomotive designed on this principle would have some advantages in comparison with a connecting-rod locomotive for the same service; but a careful study of all the requirements and conditions of any particular case would be necessary before any conclusion could be reached.

MOTOR AND CONTROL EQUIPMENTS FOR ELECTRIC LOCOMOTIVES.

By F. LYDALL, Member.

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General questions relating to the design of electric locomotives having already been discussed in a paper submitted to the Institution and printed in the *Journal*,* it may be of interest in the same connection to draw attention to some considerations relating to the electrical equipments alone.

It is not proposed to go at all deeply into the many questions of motor design that must be carefully dealt with by the designer of the equipment, as these are matters for specialists; even if the author were competent to do justice to these questions, which he does not profess to be, it would be better in his opinion to accord them separate treatment in a paper addressed principally to dynamo designers. Neither is it proposed here to go into the constructional details of the various pieces of apparatus constituting the control equipment. Putting aside these matters, however, it may be of interest to refer to a few general considerations which are applicable more especially to electric locomotives as distinguished from electrically equipped vehicles in general.

MOTORS.

Dealing first with motors for locomotives, it will be convenient to divide them into two classes, viz. geared and gearless motors. The suitability of one class in preference to the other in any particular case has already been discussed at some length in the paper mentioned above. The conclusions arrived at are that the sphere of utility of the geared motor is practically confined to locomotives of moderate speed, as, for instance, locomotives whose maximum speed never exceeds 60 to 65 miles per hour; whereas for express passenger locomotives, with which speeds up to 80 or 85 miles per hour may be reached, the gearless motor practically holds the field.

Various methods of utilizing motors in locomotives, that is of transmitting the effort exerted by them to the driving axles, have also been referred to in the same paper and need not be repeated. It is proposed only to draw attention to questions of motor capacity in relation to (*a*) gauge, (*b*) electrical system, (*c*) voltage, (*d*) diameter of driving wheel, (*e*) method of transmission, and (*f*) forced ventilation. A list given below also contains a certain amount of information about several locomotive motors built by various electrical firms or companies, which may perhaps be convenient for reference.

(*a*) *Gauge*.—It will be readily understood that a narrow gauge hampers the designer very seriously. If it is intended to adopt the ordinary form of transmission, viz. by single reduction gearing with the "wheelbarrow" type of suspension, the space available for the motor and the gearing is equal in one direction to the distance between the wheel tyres, less the necessary clearance. If with the normal-sized driving wheel the space available is insufficient to accommodate a motor of the required capacity, the only alternatives are to increase the wheel diameter or to adopt some other form of transmission. The latter of these two alternatives leads to a more expensive construction, but nevertheless it may be unavoidable.

The point is well illustrated by two locomotives both equipped by Messrs. Siemens Schuckert, one for a colliery in the North of England, the other for the metre-gauge railway line belonging to the Rombacher Hütte in Alsace. In the latter the motors are suspended on the bogies in the ordinary way, and the only departure from the usual arrangement is in respect of the wheel diameter which is greater than customary for motors of 160 h.p. capacity. This instance is of particular interest owing to the fact that each motor is designed for a voltage of 1,000 and is insulated sufficiently to withstand a pressure of 2,000 volts to earth, the supply being at 2,000 volts continuous current.

In the former locomotive, which was designed for a gauge of 26 in., the problem was to provide an equipment with a total capacity of about 175 h.p. For this purpose an 88-h.p. motor was mounted on each of the two bogies in such a position that it was not restricted in an axial

* F. LYDALL. "Electric Locomotives." *Journal I.E.E.*, vol. 51, p. 739, 1913.

direction by the wheel tyres. A jack shaft was also provided geared to the motor and coupled to the driving axles by side coupling rods. In this way a motor which with the ordinary suspension could not be got into any gauge less than 1 metre was fitted on to a truck built for 26 in. The two constructions are shown to the same scale in Fig. 1.

Another example may be mentioned, viz. the 250-h.p. single-phase motor of the 760-mm. (2 ft. 6 in.) gauge locomotive for the St. Polten–Mariazell line in Austria. In this case the motor is mounted on the top of the bogie and is geared to a jack shaft immediately below it, this shaft being connected to the three driving axles by Scotch yokes or slotted coupling rods. In this way space restrictions are eliminated.

The restrictions of gauge are of less importance in a locomotive in which gearless motors are used mounted in the body of the locomotive and driving by connecting rods and jack shafts. With this construction the motor can be made as large in diameter as desired consistent with the

Space in an axial direction being in general restricted, the tendency will naturally be towards an increase in the diameter, corresponding to an increase in the working voltage, as has already been noticed in the case of the Rombacher Hütte locomotive mentioned above.

For motors of moderate capacity, there seems no difficulty in raising the supply voltage to 2,400, as in the case of the locomotives for the Butte and Anaconda Railroad, each of which is equipped with four 300-h.p. single-reduction twin-gear forced-draught motors suspended in the ordinary way with 48-in. driving wheels. A step in advance of this is being tested on the Lancashire and Yorkshire Railway, where motor-coach equipments are being supplied by Messrs. Dick, Kerr & Co., each consisting of four 250-h.p. 1,650-volt single-reduction single-geared motors with driving wheels of 44-in. diameter, the supply voltage being 3,300. These equipments are said to work perfectly satisfactorily, but it is self-evident that in some places inside the motor the clearances between live parts and the frame

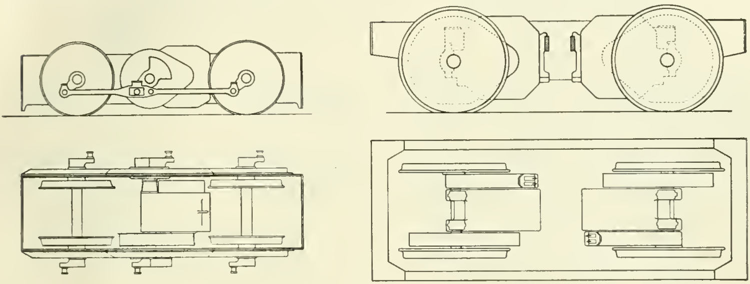


FIG. 1.

limits of armature peripheral velocity, but in an axial direction it is limited by the distance between the centres of the crank pins at the two ends of the jack shaft. With outside bearings, however, the cranks being on extensions of the journals, this is not a severe restriction.

(*b*) *and* (*c*) *Electrical system and voltage.*—Four alternative systems may be mentioned: continuous current low-tension, continuous current high-tension, three-phase alternating current, single-phase alternating current.

For continuous current, low tension may be regarded as any voltage up to 750 or 800, high tension 1,000 volts upwards, there being no cases that the author is aware of in which the voltage is between 800 and 1,000. It will be obvious that for the same capacity a high-tension motor will be larger and heavier than a low-tension motor. There is less space for armature conductors, and therefore the armature must be bigger for the same volume of copper. The commutator may be shorter if the motor is designed for a high terminal voltage, and not merely insulated for connection in series with another low-voltage motor on a high-tension supply; but this advantage is counterbalanced by the longer creeping surfaces required and the greater clearances between live parts and the frame.

must be comparatively small. But whatever the results of this experiment may be, it is certain that in the case of a locomotive where there is no objection to the motors projecting above the floor-level, the electrical designer would feel happier in making the motor with ample internal clearances, and this could only be done by freeing the motor, by one or other of the various methods available, from the restrictions of the gauge and the wheel diameter.

In considering the two alternating-current systems, the question of frequency is important. For three-phase locomotive motors, especially those operating in cascade, a low frequency is desirable. In the new locomotives for the Norfolk and Western Railway 25-frequency motors are to be used, but this is probably on account of the general tendency in the United States to adopt this frequency as the lowest standard for railway work in order to utilize the supply for other purposes at the same time.

So far as capacity in relation to weight and bulk is concerned, polyphase induction motors make a very good showing, as may be seen from several examples in the table annexed. It must be remembered, however, in comparing induction motors with motors having series characteristics, whether continuous current or single-phase alternating

current, that the induction motor is rated at its maximum speed, that is at a speed which may correspond to the maximum permissible peripheral velocity of the rotor, whereas the series motor is rated on the basis of a speed which may be, and often is, not more than half the maximum. If series motors were especially designed to give their output on the one-hour rating at their maximum speeds, they would compare very favourably with induction motors; at least the continuous-current series motor would give astonishing figures for weight per horse-power.

In practice, the single-phase motor, even at the low frequency adopted as the standard on the Continent ($16\frac{2}{3}$ or 15) is undoubtedly more bulky than the continuous-current motor. As an illustration of this, the 2,000-h.p. 600-volt motor of the Pennsylvania Railroad locomotives may be compared with the 800-h.p. single-phase motor of the Lötschberg locomotive equipped by the Allgemeine Elektricitäts Gesellschaft. The comparison is shown in Fig. 2, the two motors being drawn to the same scale.

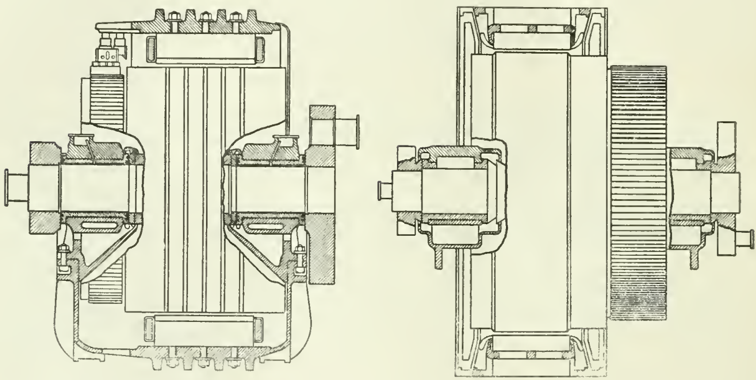


Fig. 2.

2,000-h.p. 600-volt Motor for Pennsylvania Locomotives.

800-h.p. Single-phase Motor of 1—B+B—1 Locomotive for Lötschberg Railway.

(*d*) *and* (*e*) *Diameter of driving wheel and method of transmission.*—The influence of these two factors on motor capacity has already been touched upon above.

(*f*) *Forced ventilation.*—The advantage of forced ventilation in increasing the continuous capacity is so great that it is becoming general to introduce it in locomotives of all classes except small industrial locomotives. A few figures are given in the table showing the gain in capacity due to forced ventilation as compared with radiation from the external surface of the closed motor, shown more particularly in the relation between the continuous and the one-hour ratings. The complication of apparatus involved in the provision of the blowers is not great, and no trouble in regard to maintenance need be anticipated, as the blowers and their motors can be fixed in the interior of the locomotive where they can be inspected at any time. Reference may perhaps be made in this connection to the paper by Professor Reichel,* in which the whole question of ventilation for locomotives is fully discussed.

Control Equipments.

The problems inherent in the design of a control system suitable for an electric locomotive are bound to depend upon the purpose which the locomotive is intended to serve. It may be said at once that apart from special cases an electric locomotive differs essentially from a motor coach both as to its function and as to its constitution. A motor coach, as generally understood, is a passenger vehicle with an electrical equipment. This equipment is usually designed to enable the train to be started with a high acceleration, so high in fact that it does not depend to any great extent on the gradients such as are ordinarily met with on English railways. The weight of the motor coach is determined principally by structural considerations with regard to the passenger accommodation, and partly by the weight of the electrical equipment itself, and is kept down to the lowest limit consistent with strength and the requisite capacity.

The design of an electric locomotive, on the other hand, depends on quite different considerations. In the first place, the weight is arbitrarily chosen independently of the structural strength and to a certain extent of the capacity of the equipment; on the contrary, the principal deciding factors are the adhesion necessary to enable the required tractive effort to be exerted, and the speed of travel. The first of these factors determines the weight carried by the driving wheels; the second the number and arrangement of non-driving wheels. In many cases loco-

* *Elektrische Kraftbetriebe und Bahnen*, vol. 11, p. 109, 1913.

motives are ballasted in order to bring up the total weight to the required value.

In the second place, electric locomotives are not usually intended for service in which high acceleration is required. Rapid starting is not a matter of great importance for freight trains or for long-distance passenger trains. In consequence the proportion of the weight on the driving wheels to the total weight of the train is usually much lower in the case of trains hauled by electric locomotives than in the case of multiple-unit motor- and trailer-coach trains.

For example, for freight trains the ratio might perhaps be as low as 1 to 20; whereas for multiple-unit trains it would seldom be less than 1 to $2\frac{1}{2}$, or 1 to 3.

This difference in the ratio of adhesion weight to total weight has a marked influence on the control system, as will be seen the moment the question of starting on gradients is considered.

The following general statements with regard to heavy traction by steam or by electric locomotives will be admitted by railway engineers.

(*a*) The weight on a pair of driving wheels is generally not far from the maximum permissible weight as determined by the strength of the track, bridges, etc.

(*b*) A locomotive is utilized to the greatest advantage when it is coupled to the heaviest train with which it is able to deal; that is, haul at the regulation speed on the line selected, start on the steepest rising gradient, and stop on the maximum falling gradient.

It will perhaps be best to explain the influence of these points on the control system by considering a simple example.

Let it be assumed that the maximum weight per axle of the locomotive is 16 tons; and take the case of an articulated 4-axle 64-ton locomotive, each half of which is equipped with one continuous-current motor, driving through single-reduction gearing and coupling rods. Suppose also that the steepest gradient on the line is 1 in 90. Fig. 3 shows the outline of the locomotive, and Fig. 4 gives the performance curves of each motor.

In order to study the capabilities of the locomotive it is necessary to make some reasonable assumption as to the maximum value of the coefficient of adhesion. Let it be assumed that this value is 1 to 4, in other words that the greatest tractive effort that can be exerted by the motors without causing the wheels to slip is 64/4 tons (= 16 tons) measured at the tread of the driving wheels (not at the draw-bar).

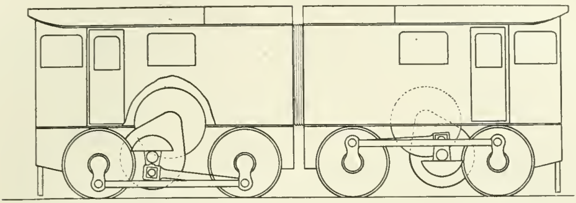


Fig. 3.

Now the variations of the tractive effort exerted by the motors during the progress of the controller obviously depend on the number of steps in which the controlling resistances are switched out with motors in series and in parallel. Whatever the variation may be, the current on each position of the controller must be allowed to fall so far that when the next step of resistance is switched out the current does not increase beyond the value corresponding to the maximum permissible tractive effort. If the load behind the locomotive when travelling up the specified gradient is too great, the current will never fall sufficiently to permit the controller to progress without causing the wheels to slip. It is of course well known that when the wheels slip the tractive effort is much less than while the wheels adhere to the rails. If, therefore, the load is excessive, the locomotive will be unable to start the train and gather speed on the gradient, although it may be perfectly capable of maintaining full speed up the gradient if the train has already been started on the level or on an easier gradient.

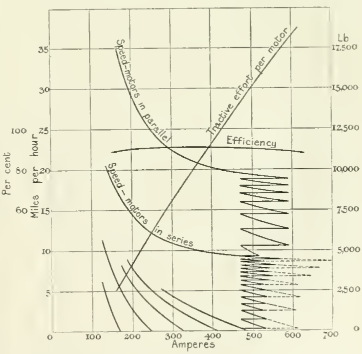


Fig. 4.—Performance Curves of 550-h.p. 1,300-volt C.C. Motor

Thus suppose the locomotive mentioned above is coupled to a train weighing W tons, and assume that the tractive resistance of the whole train during the start is 7 lb. per

ton, then the tractive effort required to maintain speed on the gradient of 1 in 90 without acceleration will be—

$$(W + 64)\left[\frac{2240}{90} + 7\right]$$

$$= (W + 64)\ 32 \text{ lb.}$$

$$= \frac{W}{70} + 0{\cdot}915 \text{ ton.}$$

This then will be the theoretical lower limit of the variation of tractive effort during the start.

For example, supposing the number of steps in the control system is such that with an upper limit of 16 tons the lower limit is 12·5 tons, then the maximum train weight permissible will be given by the equation—

$$\frac{W}{70} + 0{\cdot}915 = 12{\cdot}5,$$

from which W = 810 tons.

It is hardly practicable, however, on the assumptions made above, to work with a trailing load as high as this. If this load were coupled to the engine and an attempt were made to start up on the specified gradient, each step of the control would occupy an inordinate time before the motor current fell far enough to permit the controller to advance to the next step. This is fairly obvious from the speed time curve in Fig. 5, which shows how the acceleration varies from a fairly high value down to almost zero on each position of the controller. If then the maximum theoretical load is attached to the locomotive, the acceleration must actually reach zero on each position of the controller, which is of course impracticable. In practice, therefore, the load must be limited to something less than the theoretical maximum value. For the following reason the reduction will depend on the gradient. If the tractive

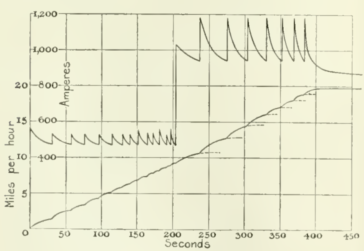


FIG. 5.—Acceleration Curve of 804-ton Train. 1 in 100.

resistance is small compared with the force of gravity on the gradient, the pull required to maintain speed on the gradient can be calculated with fair accuracy. If not, the calculation will depend to a large extent on a correct forecast of the tractive resistance. Even a correct forecast, however, is not sufficient, since the tractive resistance differs between wide limits under varying conditions.

For example, suppose the gradient in question is 1 in 50, and the estimated tractive resistance is 7 lb. per ton. Then the pull corresponding to steady speed will be

$$\frac{2240}{50} + 7 \text{ lb. per ton} = 51{\cdot}8 \text{ lb. per ton.}$$

An error of 10 per cent in the tractive resistance will only involve an error of 1·25 per cent in the total.

If, however, the gradient were 1 in 200, an error of 10

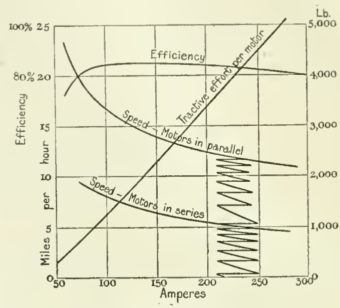


FIG. 6.—Performance Curves of 100-h.p. 500-volt C.C. Motor.

per cent in the tractive resistance would lead to an error in the total of 3·8 per cent.

The only safe way then is to estimate the tractive resistance on the high side and allow a margin beyond the calculated value to ensure that the starting period is not unduly prolonged.

For example, in the case illustrated in Fig. 5, the theoretical maximum value is 810 tons, and the actual value on the basis of which the curves have been drawn is only 740 tons.

The number of steps in the controller or control system will depend on the characteristics of the motor in question. If the magnetic circuit of the motor is not highly saturated on that part of its range which is used during starting, and if the resistance of the motor is relatively high, the number of steps necessary to keep the torque variation within moderate limits is not likely to be excessive. The greater the saturation and the lower the internal resistance, the greater will be the number of steps.

These two factors can be combined in one, viz. the slope of the speed curve at the working range. The greater the slope, the smaller the number of steps.

This slope being the resultant of the two factors will vary with different motors. In a general way one may say that the bigger the motors, the lower will be the internal resistance, and therefore the less the slope and the greater the number of steps. This is illustrated by the comparison in Figs. 4 and 6, the former of which shows the starting curves for a 550-h.p. motor and the latter those for a 100-h.p. motor, the same percentage variation of torque being permitted in both cases.

This comparison is perhaps worth consideration when

determining the most favourable motor equipment for a given locomotive. If a single large motor be chosen instead of, say, four small motors of the same aggregate capacity, in order to arrive at the same value of the maximum permissible load a more elaborate control system must be installed. This is, however, comparatively a small point.

It is also worth remarking that the question of self-induction in the motor windings does not enter into the consideration of the problem. In the case of a tramcar starting on the level, under ordinary circumstances the entire starting period may not last more than 6 seconds, and therefore the time spent on each notch of the controller is so short that the variations of the motor current may be considerably influenced by self-induction. In the case of a locomotive starting with its maximum load on a steep gradient, the accelerating period may last from 5 to 10 minutes, so that the influence of self-induction may be ignored. It is therefore necessary to consider the matter carefully, as no help can be expected from this source.

On the other hand there are two factors which make for some uncertainty as to the precise fluctuations of the torque during the accelerating period, viz. the variation of the supply voltage on the overhead line, or on the third rail as the case may be, and the variations in the resistance values of the controlling resistances due to the rise in temperature. The first of these tends to reduce the fluctuations, as the supply voltage will generally fall slightly as more current flows through the motors. The second is very uncertain, the temperature of the resistances depending on the working conditions, etc.

So far the question has been discussed only in relation to continuous-current motors controlled in the well-known way by means of inserted resistances cut out in successive steps. To a certain extent the same problem is met with when alternating-current motors are employed either with rheostatic control or with voltage control obtained by drawing current from successive tappings of a transformer. The actual variation of motor torque from step to step will, however, depend upon a factor which is absent in continuous-current working, viz. the effect of the self-induction of the motor windings on the motor characteristics. This effect, so far as the speed-current curve is concerned, is similar to that of a large increase in the internal resistance of the motor, and therefore greatly reduces the fluctuation of the torque for any given number of steps.

As an example of this effect, the speed curves in Fig. 7 may be compared with those in Fig. 4. The difference in the number of steps for the same fluctuation of torque in the two cases is obvious.

Going back to the general question, it is evident that the irregularity of the effort exerted by the motor equipment of an electric locomotive is a disadvantage which under certain circumstances reduces the usefulness of the locomotive. It may be compared with a very similar characteristic of the steam locomotive, the tractive effort of which varies with the positions of the cranks. There is, however, this difference between the two cases: the tractive effort of the steam locomotive fluctuates under all conditions, whereas that of the electric locomotive is uniform on any single step of the controller whether intermediate or final so long as the speed remains constant, and therefore at the worst fluctuates only during the actual starting period.

The question may be raised as to whether this disadvantage in the electric locomotive cannot be overcome by means which are commercially practicable. For continuous-current equipments variable voltage must be obtained by some form of motor-generator, the motor taking current from the power supply, and the generator delivering current at a suitable voltage to the driving motors, the voltage being varied as required by the excitation of the generator.

This method is open to the great objection that the motor-generator is practically a sub-station installed in the

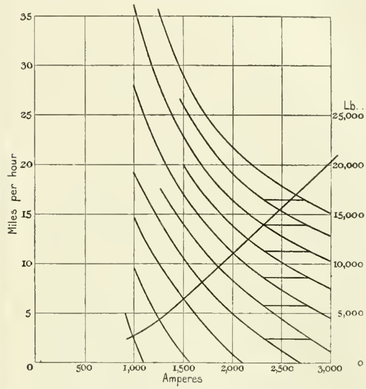


FIG. 7.—Speed Curves of 700-h.p. Single-phase Railway Motor.

locomotive, and is extremely bulky and expensive, and costly to maintain.

The capacities of the machines may be considerably reduced, however, by employing them only during the starting period, both machines running idle or being switched out altogether during the continued working of the locomotive. For example, the motors may be arranged for series and parallel connection in the ordinary way, and the motor-generator may be used to reduce the line pressure by interposing in the circuit between the motors and the line a gradually decreasing back electromotive force. With this arrangement the size of the motor-generator will be determined largely by its heat capacity in relation to the output required for the comparatively very short time of starting and accelerating.

In any case, however, it is highly probable that this solution of the difficulty is more expensive and complicated than the simple expedient of multiplying the number of resistance steps and the corresponding contactors so far as may be necessary.

The case is quite different, however, with large locomotives equipped on the single-phase alternating-current system. Voltage variation can be very conveniently pro-

vided without using rotating machinery in the case of alternating current. Definite steps of voltage can be obtained simply by providing taps on the secondary winding of the step-down transformer, and there are various well-known methods at present in use whereby the maximum number of voltage steps is obtained with the minimum number of contactors.

In spite of the advantages of these different schemes, however, it is not practicable to go very far in the direction of fine graduation. In practice, owing to the requirements of single-phase motor design, the voltage even at full speed is seldom more than about 300. It is also customary to employ large motors for these locomotives, and consequently the motor current which must be dealt with by the controlling contactors may be very heavy.

For example, the 1—C—1 locomotive equipped by Messrs. Siemens Schuckert for the Prussian State Railway, contains a single 1,800-h.p. motor. The one-hour current of this motor, assuming the terminal pressure to be 300 volts, will be in the neighbourhood of 6,000 amperes. The indefinite multiplication of contactors suitable for dealing with this current, even if the control is so arranged that the current is equally divided between four contactors, is not a prospect that possesses any attraction for the designer, and it is only natural that he should look round for an alternative scheme which will provide the desired fine adjustment of speed and tractive effort without the necessity of a large number of parts all of which require attention from the maintenance staff.

The alternative is to use an induction regulator or variable transformer in which the primary winding is mounted on a movable core arranged so that it can be turned round into any position relative to the fixed secondary winding, the mutual inductance and therefore the ratio of transformation being varied as gradually as desired from zero to a positive or negative maximum.

This method has the great advantage of simplicity, as it entirely eliminates the contactors and the tappings on the low-tension side of the main transformer. It has, however, also the serious disadvantage of introducing into the locomotive a bulky and heavy additional piece of apparatus which adversely affects the efficiency and the power factor of the equipment.

For example, take the case of a locomotive equipped with two motors each rated at 1,250 h.p. at 300 volts (one-hour rating).

The corresponding current taken by the two motors is about 7,700 amperes. Suppose the voltage regulation required for the proper working of the locomotive is from 120 to 300. Then the main transformer must be wound for 210 volts, and the induction regulator must be wound for 90 volts. That is to say, the capacity of the regulator must be approximately—

$$\frac{7700 \times 90}{1000} \text{ kw. or nearly 700 kw. (one-hour rating).}$$

A regulator of this capacity must necessarily weigh a good deal and occupy a considerable space, and it must be observed that its introduction into the equipment does not lead to any reduction in the size or capacity of the main transformer unless a combined transformer and induction regulator is used, as the whole of the energy taken from the high-tension line must be transformed down to the low voltage however the motors are controlled.

An alternative method, which is in reality a combination of the contactor system and the induction-regulator system, was worked out by the present writer about 8 years ago, and has been adopted on several of the single-phase locomotives equipped by Messrs. Siemens Schuckert for the Prussian State Railways.

This method consists in the employment of a small induction regulator combined with a number of contactors which control the connections from the motors to the tappings of the low-tension winding of the main transformer. The function of the regulator is to increase the voltage at the terminals of the main motor or motors as gradually as may be required until the voltage corresponding to the next higher tapping of the transformer is reached. At this point a change is made in the circuit connections by closing a fresh contactor and opening the one previously closed, which operation can be effected without giving rise to any local short-circuits or serious sparking or difficulties of any kind. If the number of contactors employed is, for example, four, the capacity of the regulator is reduced to one-quarter; if six, it is reduced to one-sixth. Whatever the number and the consequent reduction in size, however, it is possible and easy to ensure that the voltage variation shall be as gradual as may be desired.

There are various ways of carrying out this method, but probably the simplest is shown, quite diagrammatically, in Fig. 8. In this diagram six tappings and six contactors are shown. The voltage of the secondary winding of the

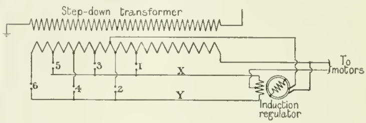


FIG. 8.

regulator through which the main current flows is exactly equal to the voltage between any two adjacent tappings. Current passes into the secondary winding at either end according to which end is connected to a closed contactor and passes out from the middle point to the motors. The tappings are connected through the contactors alternately to two leads x and y; 1, 3, and 5 being connected to x, and 2, 4, and 6 to y. The ends of the regulator secondary are permanently connected to these leads x and y. For the minimum voltage, contactor 1 is closed, the primary of the regulator being in such a position that the voltage induced in the secondary opposes the voltage of the main transformer. To increase the voltage, the regulator is turned round until the voltage induced in its secondary is added to the voltage of the main transformer. At this point contactor 2 is closed, and contactor 1 opened, and the circuit is in this way re-arranged so that the regulator voltage opposes the main transformer voltage corresponding to the second tapping. The regulator is then turned round again as before and the process repeated until the full voltage is reached.

Control diagrams of this and other systems are given below.

Referring once more to continuous-current locomotives, the importance of avoiding shocks also has its influence on

the control equipment. During the starting period there are at least two occasions when shocks of greater or less severity are possible and are to be avoided, so far as may be, in the interest of the couplings between wagons. The first occasion is when the current is first switched on to the driving motors. If all the couplings were taut it would not matter very much if the full starting effort of the motors were exerted immediately. But if, as is very frequently the case with goods and mineral trains, the couplings are slack, it is strongly advisable that the initial pull of the locomotive should be only sufficient to take up the slack in the couplings before the train is accelerated. In this connection it must be observed that trains may be made up with the full number of wagons or with very few, and in both cases care must be taken to avoid a shock. The control equipment must therefore be arranged so that the tractive effort on the first notch or step of the controller is relatively quite small.

It should also be remembered that if the starting acceleration of the locomotive when working light is too great it may be difficult for the locomotive driver and his mate to keep their feet. For example, suppose a 64-ton locomotive is designed to exert an average tractive effort during the start of 23,000 lb., the acceleration which this effort would produce with the locomotive alone would be something over 3 miles per hour per second. It would be almost impossible for a man to stand up against this acceleration if it were applied suddenly. It would therefore be necessary to install sufficient resistance in the locomotive to reduce the tractive effort on the first step to something like 5,000 lb., which would produce an initial acceleration of about 0·6 mile per hour per second.

The other occasion on which a shock is to be avoided is during the transition in the grouping of the motors from series to parallel. This can be effected by employing the well-known bridge system of control, in which the full torque is maintained by the driving motors right through the transition stage, subject of course to the fluctuations that occur to the same extent during the whole of the starting period.

Provided only two motors or two groups of motors are used in a single equipment, the two being connected successively in series and in parallel, there is no difficulty at all in arranging the control equipment on the bridge system. It is otherwise, however, when there are four motors to be arranged in three groupings, viz. series, series-parallel, and parallel. It is a simple matter to arrange one of the transitions on the bridge method, but for the other it is hardly practicable, though theoretically quite possible, to pass through the transition without a momentary reduction of the tractive effort to quite a low value. An example is given below in Fig. 9 which shows the control diagram of the 4-motor equipment of the New York Central continuous-current locomotives.

Dealing now with the arrangement of the controlling resistances, it is to be observed that with the same number of steps the fluctuations of torque are much greater in the series than in the parallel grouping. To put it in another way, in order to keep the fluctuations within given limits as mentioned in the beginning of this paper, it is necessary to provide more steps for cutting out resistance in the series grouping than in the parallel.

This can be done most conveniently, and without involving the provision of any more contactors, by arranging the equipment on the bridge system, in which each motor or group of motors has its own set of resistances and contactors for cutting out these resistances in steps, and by cutting out one section of resistance from each of the two sets alternately while operating in series and cutting out the same sections simultaneously when operating in parallel. A good example of this is provided by the control equipment of the 2—B+B—2 double locomotives of the Pennsylvania Railroad, the diagram of which is given in Fig. 10.

The various points mentioned above include most of the considerations to which attention may be drawn in connection with what may be called the theoretical side of locomotive control. The subject is of course by no means exhausted, but it has been the author's wish to bring forward the principal points in which locomotive control differs from the fairly well-known systems of multiple-unit motor-car train control.

Turning now to the practical side, there is not a great deal that can be said without entering upon many questions of detailed design which would be out of place in this paper. The author is not in a position to give working drawings of the various items of locomotive control equipments, and he does not think they would be of very wide interest if they were published, as comparatively few firms at present undertake the manufacture of such apparatus.

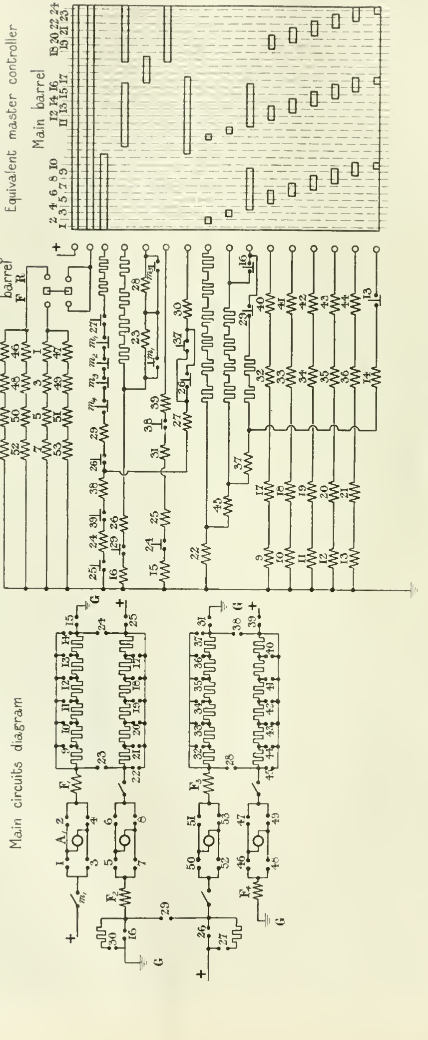
The points that may be mentioned and discussed include the following: Main controlling resistances, contactors, reversers, circuit-breakers, apparatus for automatic working, and induction regulators.

The material most generally used for the main controlling resistances in continuous-current locomotives is cast iron. This can be either plain grey cast iron, or an alloy which contains certain ingredients giving qualities of elasticity and high resistance. For small currents one of the alloys is generally employed, but for large currents simple cast iron may be used, provided care is taken in selecting thoroughly sound castings.

There is no difficulty in obtaining grids having a specific resistance of about 80×10^{-6} ohms per cubic centimetre, and capable of carrying intermittently currents from 30 amperes to 400 amperes or higher still if necessary.

The grids are usually left plain without any rust preventive. In some cases they are tinned or coated with aluminium paint; but such coating reduces considerably the radiating capability of the grids. The paint, moreover, seldom lasts very long, as it tends to flake off under the influence of the heat and the vibration. Further, if the locomotive is kept in service there is little tendency for the grids to rust, as any moisture which may settle on them very quickly dries off as soon as current passes.

The determination of the resistance values in any particular case is not very difficult if the motor characteristics are known. On the other hand it is extremely difficult to decide on the capacity of the resistances for a locomotive unless the conditions of service are very precisely stated. As a general rule it is impossible to lay down a set of conditions such as can easily be given for multiple-unit trains in urban or suburban service. A locomotive can be most irregular in its working. It may start from rest and reach half speed, the wheels may then slip and the acceleration period may be indefinitely prolonged,



Control circuit resistances.

Operating coil of contactor I.

Interlock on contactor I which is closed when contactor is closed.

" " " " " open " " " "

" " motor cut-out switch I which is closed when switch is closed.

" " " " " " " open " " " "

NOTE:—The Master Controller consists of a reversing barrel as shewn, and two main barrels geared together so that one makes approximately three revolutions while the other is making one.

FIG. 9.—New York Central 4-Motor Locomotive.

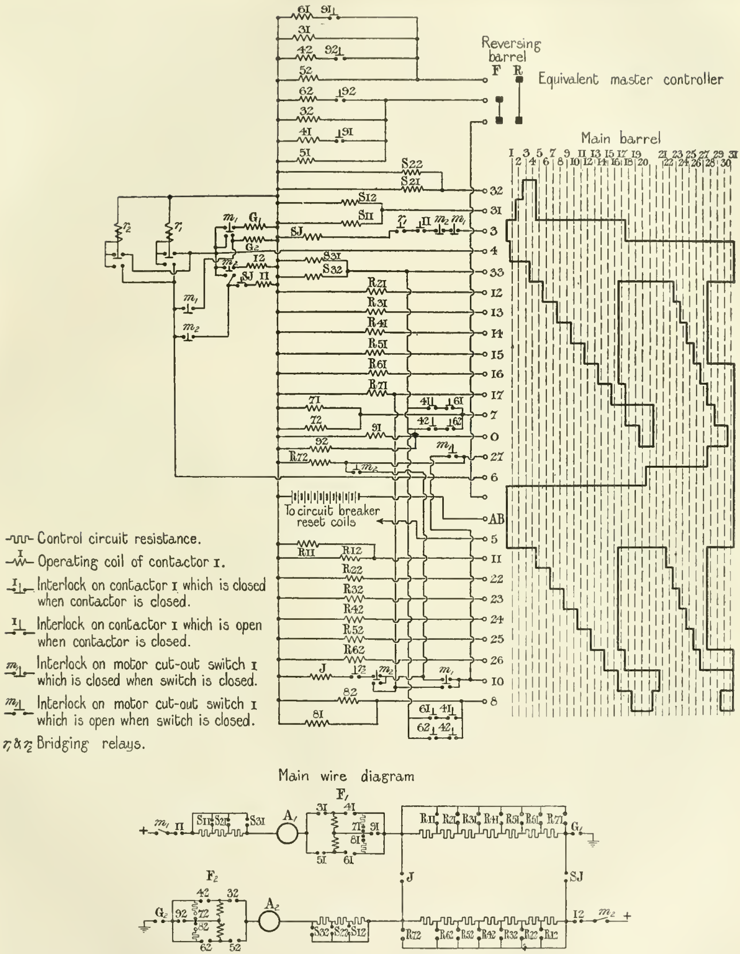


FIG. 10.—Control Diagram for Pennsylvania Railroad Locomotive.

or other circumstances may arise which will prove still more severe on the resistances.

The only rule which will provide for perfect security against overheating is to make the resistances so large that continuous running on any step of the controller is possible without giving rise to excessive temperatures.

There is no difficulty in meeting this condition in the case of a low-power locomotive, and there is everything in its favour. Ballast to a greater or less extent is almost always fitted in such locomotives to obtain sufficient adhesion, and no harm is done if some of this is in the form of resistance grids.

For high-power locomotives it is practically impossible to attain to this ideal on account of the space required. Blocks of resistance cannot be piled up in several layers, otherwise the heated air from the lower blocks prevents the cooling of the upper layers. It is also important that easy access is provided to all the grids so as to facilitate inspection and maintenance. It is possible that a grid may very occasionally break and in so doing open the main circuit. It should be an easy matter to locate the breakage and replace the damaged grid. It is also advisable to blow off occasionally the dust and dirt that collect on the insulating surfaces of the supports, otherwise there will be a breakdown of insulation sooner or later.

For such locomotives the only thing to be done is to examine each case separately and insert as much resistance as can be conveniently disposed in the space available. It may also be necessary to take into consideration the question of forced ventilation for the resistances. This is of course a complication, and the question whether it is justified cannot be settled without a full knowledge of the circumstances.

On the Continent liquid rheostats have been used in one or two cases, principally for three-phase locomotives. Such an arrangement will probably not appeal to English engineers, although it possesses some definite advantages, principally in the facility with which the resistance can be varied under air pressure, and in the absence of a large number of connecting wires, contactors, etc. It has, however, disadvantages which offset these features, viz. that the resistance depends on the strength of the solution, which may alter considerably in a short time if the rheostat is worked hard due to evaporation of the solvent; and further, that after the resistance has once been cut out by filling the chamber with the fluid quite an appreciable time is required to empty the chamber again in order to prepare the rheostat for further use. For continuous-current locomotives it would be difficult to utilize such an arrangement, and for single-phase locomotives a rheostat finds no place.

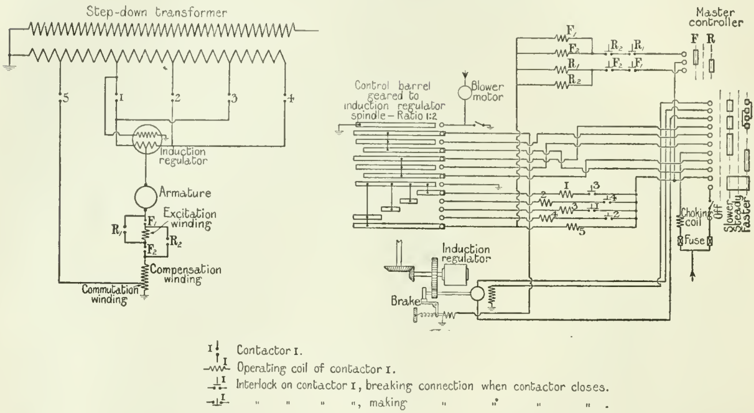


FIG. 11.—Control Diagram, Siemens 2—B—1 Locomotive. Dessau–Bitterfeld.

With regard to control apparatus proper, such as contactors, reversers, circuit-breakers, etc., there is this to be said, that whereas in equipments for motor coaches the designs are practically determined by the requirements of multiple-unit working, no such condition necessarily applies to locomotive control-apparatus. In motor coaches all the apparatus is operated by remote control through the agency of the master controller and possibly one or two auxiliary switches. In electric locomotives, although in the first instance it is often thought best to make provision for multiple-unit working, it frequently happens that such provision is abandoned or dispensed with. For example, on the New York Central locomotives, which were originally arranged with all necessary appliances for coupling two together and controlling both from a single controller, it was found that the possibility of working in this way was

not taken advantage of, and the electrical couplers were permanently disconnected.

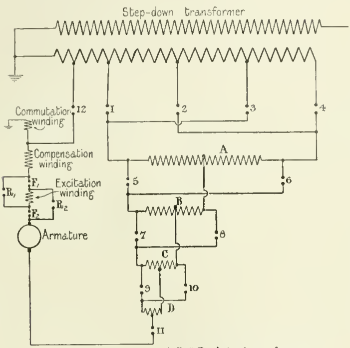
There are, of course, cases in which this provision cannot be dispensed with, for example on the 1—C+C—1 freight locomotives for the Kiruna-Riksgraensen line in the North of Sweden. These locomotives are intended for hauling mineral trains weighing 2,000 tons, there being one double locomotive in front and another at the rear of the train. Under these conditions it is important that the two locomotives should not work independently, otherwise there would be frequent cases of breakage of couplings. The control equipments are therefore specially designed so that both can be operated absolutely synchronously from the master controller in the leading locomotive, electrical connections being provided by a control cable with the usual couplers from front to back of the train.

This condition is, however, up to the present somewhat nected by a chain with a crank arm pivoted on the front wall of the locomotive.

In the 2—B—1 locomotive equipped by the Allgemeine Elektricitäts Gesellschaft for the same line, the main switch is operated in a similar manner, and there is a single master controller in the centre of the locomotive operated by means of a hand wheel in either of the two driver's cabs through rods and bevel gearing.

Numerous other examples could be quoted, but it is sufficient to draw attention to the fact that advantage has been taken of the conditions under which locomotives work to break away from stereotyped methods of designing control equipments in the direction of simplicity and directness of operation.

Turning now to a rather more detailed consideration of locomotive control-apparatus, it must be admitted that in many cases there is nothing to distinguish the various items



Notch	Contactors closed														
	1	2	3	4	5	6	7	8	9	10	11	12	F_1	F_2	R_1	R_2
1	o	o			o		o		o		o	o	×	×	+	+
2	o	o			o		o			o	o	o	×	×	+	+
3	o	o			o			o		o	o	o	×	×	+	+
4	o	o			o			o	o		o	o	×	×	+	+
5	o	o				o		o	o		o	o	×	×	+	+
6	o	o				o		o		o	o	o	×	×	+	+
7	o	o				o	o			o	o	o	×	×	+	+
8	o	o				o	o		o		o	o	×	×	+	+
9		o	o			o	o		o		o	o	×	×	+	+
10		o	o			o	o			o	o	o	×	×	+	+
11		o	o			o		o		o	o	o	×	×	+	+
12		o	o			o		o	o		o	o	×	×	+	+
13		o	o		o			o	o		o	o	×	×	+	+
14		o	o		o			o		o	o	o	×	×	+	+
15		o	o		o		o			o	o	o	×	×	+	+
16		o	o		o		o		o		o	o	×	×	+	+
17			o	o	o		o		o		o	o	×	×	+	+
18			o	o	o		o			o	o	o	×	×	+	+
19			o	o	o			o		o	o	o	×	×	+	+
20			o	o	o			o	o		o	o	×	×	+	+
21			o	o		o		o	o		o	o	×	×	+	+
22			o	o		o		o		o	o	o	×	×	+	+
23			o	o		o	o			o	o	o	×	×	+	+
24			o	o		o	o		o		o	o	×	×	+	+

× For forward running.
+ " backward " .

A.B.C.D. Auto-transformers.

FIG. 12.—Control Scheme originally proposed for Siemens 1—C+C—1 Locomotive. Kiruna-Riksgraensen.

exceptional, the more usual arrangement being that the electric locomotive is a single unit suitable for hauling trains of specified weights in the same way as steam locomotives. Under these circumstances the necessity for remote control for all switchgear and apparatus constituting the control equipment is not apparent. In many cases advantage can be taken of this to arrange the main circuit-breaker and perhaps the reversers for hand operation by means of levers, hand wheels, and geared shafts. When very large units have to be dealt with, this possibility may sometimes greatly facilitate the design and construction of the apparatus.

Several of the single-phase locomotives built on the Continent have been designed on this principle. For example, in some of the locomotives equipped by Messrs. Siemens Schuckert for the Dessau-Bitterfeld line, the main high-tension oil switch is operated by a lever which passes through the partition dividing the high-tension chamber from the driver's compartment, and the reverser is moved into one position or the other by means of a shaft con-

in the equipment from similar items in the control equipments of multiple-unit trains except size and quantity. The contactors are more numerous and are larger as is necessary to deal with the higher current. The circuit-breakers, fuses, etc., are designed on well-known lines, merely adapted to altered conditions.

Various changes may, however, be noticed, particularly in the locomotives built in the United States. For example, reversers are commonly eliminated and replaced by the necessary number of contactors. In one way this is a simplification, as it is not usually thought necessary to interlock the reversing contactors with the series, bridge, and parallel contactors as is generally the case with barrel-type reversers; on the other hand, the number of contactors is considerably increased. Except on the score of expense, the modification has much to recommend it.

Circuit-breakers for continuous-current locomotives do not call for any special remark except that on high-voltage systems the circuit-breaker must not only be substantial

but should also be allowed plenty of room in which the arc may spread. Where the high-voltage continuous-current supply is distributed by means of an overhead line, it is advisable that the arc formed on breaking a heavy overload or a short-circuit should not be violently disrupted by means of a strong magnetic blow-out, otherwise there is a liability for surges to be set up in the overhead line. In order to provide for plenty of space in which the arc may be gradually extinguished, the circuit-breaker may be fixed on the roof of the locomotive. If there is plenty of room in the body of the locomotive, the circuit-breaker may be housed in an insulated chimney with an opening through the roof covered by a hood. The latter plan, if it can be arranged, is more convenient, as it obviates the necessity of getting on the roof to examine or clean up the switch contacts.

On alternating-current locomotives, the circuit-breakers are usually oil switches similar to those used in generating stations, but adapted to fit into the locomotive.

In the past there has been very little automatic control apparatus in this country. Whatever its merits or demerits in connection with multiple unit trains, it seems to the author that for locomotives, especially freight locomotives, there can be no question as to the benefits to be gained from taking the regulation of the tractive effort at starting out of the hands of the driver. The foregoing consideration of the starting conditions will make this evident. It seems, therefore, rather remarkable that practically nothing has been done in this direction either in the United States or on the Continent. So far as the author is aware, the only cases where automatic control is employed are on the three-phase locomotives for the Simplon tunnel and the Italian railways.

The author is strongly of the opinion that if the limit switches are adjustable, and if the control equipment can be changed over without difficulty or complication from automatic to hand control whenever circumstances require such a change, there is everything to be gained by relieving the driver of the necessity of watching the ammeter and setting him free to attend to the signals and to his other duties.

Coming now to induction regulators for controlling single-phase railway motors, the main point to which attention may be drawn is the necessity for very substantial construction. Except when the relative positions of the primary and secondary windings are such that the mutual induction is zero, there is a very considerable torque produced by the action of the magnetic field and the current in the secondary winding. Moreover this is neither a continuous nor a uniform torque. On the contrary, as there is only a single phase in the magnetic field, the force fluctuates at twice the frequency of the supply between zero and maximum values. It is clear, therefore, that a fairly powerful motor is needed to operate the regulator; and the reduction gearing between the motor and the regulator must be of a very substantial nature.

Some trouble has been experienced with regulators of this type due to breakage of the gears which were designed before the effect of the powerful fluctuating torque was fully realized. Any sudden overload or short-circuit in the main motors is bound to set up a tremendous force in the induction regulator, and the whole of this is transmitted to the teeth of the gear wheel.

The advantages and disadvantages of induction regulators as compared with contactors has recently been considered very thoroughly on the Continent in the light of the experience acquired with the locomotives already in service for some time. The general tendency seems now to be setting towards the use of contactors exclusively for locomotives however large. This has been the practice all along in the United States and has much to recommend it. In case of a bad short-circuit, protection is afforded by the main circuit-breaker, the contactors being unaffected if the circuit-breaker is capable of dealing with the short-circuit immediately and effectively. In the case of an induction regulator equipment there is in addition to the demand on the powers of the circuit-breaker a very severe shock on the mechanical parts of the regulator.

Apart from this argument the time element must also be taken into consideration. The action of a contactor may be regarded as practically instantaneous, and in case of momentary failure of the supply all the contactors will open, and the control system can easily be arranged in such a way that they will not close again except by notching up from the first position of the master controller. In this way protection is provided against sudden rushes of current. With the induction regulator, or indeed with any other controlling mechanism operated by an auxiliary motor, such as for example the drum-type controller of the new Lötschberg single-phase locomotive, similar protection can be provided, but the process is comparatively slow and cumbersome.

On the other hand, the induction regulator undoubtedly possesses the advantage already mentioned of fine graduation in the regulation of the speed and tractive effort of the locomotive, which can only be obtained with contactors by multiplying the number of contactors and operating circuits and by enlarging the master controller.

Opinions have been expressed in favour of replacing contactors as far as possible with motor-driven drum switches, on the score of the high cost of maintaining the contacts and operating parts of the contactors. The use of a drum controller for heavy locomotives is only made possible, however, by removing from the drum all possibility of arcing at the contacts and concentrating the arcs on one or more special switches operated by some means or other in synchronism with the rotation of the drum. It would appear, however, that if a given number of arcs have to be dealt with, there is no great disadvantage in spreading them over a number of special contacts designed for that purpose. These contacts are bound to require less frequent attention and renewing than a single switch which does the whole of the work. There is also the auxiliary motor to be considered as against the operating coils of the contactors.

Most engineers will agree that the fewer auxiliary motors there are in a locomotive the better. So far as single-phase locomotives are concerned, the supply of current at a voltage suitable for small motors is quite a simple matter, as there is usually an auxiliary transformer which can be tapped as required. With continuous-current locomotives, however, especially when the supply voltage is higher than 600 volts, the auxiliary motors must be fed either from the main supply direct, or from the dynamotor or motor-generator. In either case the voltage is probably incon-

TABLE OF LOCOMOTIVE MOTORS—GEARED AND GEARLESS

	Designation	Manufacturer	Railway	Electric Supply	Natural Ventilation: One-hour Output	Natural Ventilation: Continuous Output	Forced Ventilation: One-hour Output	Forced Ventilation: Continuous Output	Gearing or Transmission	Gauge	Wheel Diameter	Locomotive Speed in m.p.h.: At One-hour Rating	Locomotive Speed in m.p.h.: Max.	Weight of Motor	Remark
GEARED.	g.D. 120 w.	Siemens	Colliery	500 v. C.C.	h.p. 100	80†	h.p. —	—	single redn.	2' 2"	900 mm.	7	26*	1,975 kg.	Motor geared to jack-shaft driving by side rods
	g.D. 170 w.	Siemens	Rombacher Hutte	2,000 v. C.C.	160	70†	—	—	"	metre	1,250 mm.	13	25*	3,510 kg.	Each motor wound for 1,000 volts, insulated for 2,000 volts
	G.E. 209	G.E. Co.	Baltimore & Ohio	600 v. C.C.		—	300		single redn. twin gears	4' 8½"	48 in.	—	35*	—	Gear ratio 4·37 : 1. Articulated bogie locomotive
	No. 410	Westinghouse	N.Y.N.H. & H.	single-phase 6,000 v. 25 ~		—	192	114 h.p.	"	"	63 in.	8*	—		
	No. 409A	Westinghouse	N.Y.N.H. & H.	600 v. C.C. & 6,000 v. 25 ~	—	—	170	145 h.p.	single redn.	"	63 in.	—	60*	11,900 lb. per pair	Gear ratio 92 : 22. Motors mounted in pairs with single gear wheel
	W.B.M. 280	Siemens	Seebach-Wettingen	single-phase 15,000 v. 15 ~	225				"	"	1,100 mm.	26	45*	3,100 kg.	Gear ratio 3·72 : 1
		A.E.G.	Oranienburg	single-phase 6,000 v. 25 ~	—	—	350	245 h.p.	"	"	1,400 mm.	—	37·5*	—	Weight of complete equipment with 4 motors, 27 tons
	G.E. 209/300	G.E. Co.	Butte-Anaconda	2,400 v. C.C.	—	—	300	250 h.p.	single redn. twin gears	"	48 in.	14*	—	—	Gear ratio 87 : 18. Weight of complete equipment 23·4 tons
	G.E. 506	G.E. Co.	Cascade Tunnel	three-phase 6,000 v. 25 ~		—	505	397 h.p.	"	"	60 in.	15	15·5	14,950 lb.	Gear ratio 4·26 : 1. Motor voltage 500 volts
		Siemens	St. Polten-Mariazell	single-phase 6,000 v. 25 ~	250	—	—	—	single redn.	760 mm.	800 mm.	—			Single motor on each bogie, driving by gearing and Scotch yokes
		Jeumont	Midi, France	single-phase 12,000 v. 16⅔ ~	500	400 h.p. (6 hours)		—	"	4' 8½"	1,400 mm.	27	47*	—	Gear ratio 2·72 : 1. Flexible coupling
		Westinghouse	Norfolk & Western	single-phase 11,000 v. 25 ~	—	—		630 h.p.	single redn. twin gears	"	63 in.	28	28	—	Twin 3-phase motors driving jack shafts
		Oerlikon	Lötschberg	single-phase 15,000 v. 15 ~	1,000	—		1,000 h.p.	single redn.	"	52½ in.	26	43·5	13·5 tons	Gear ratio 3·25 : 1
		Oerlikon	Lötschberg	"	1,375 1,250	1,000 h.p.	1,500	1,250 h.p.	"	"	53 in.	31	46·5	14 tons	Gear ratio 2·23 : 1. 1 E 1 loco—two geared motors and Scotch yokes.
		Bergmann	Silesian	"	—	—	—	1,250 h.p.	"	"		34‡	62	13 tons*	2 B + B 1 locomotive. Weight includes the gearing
GEARLESS.		Westinghouse	N.Y.N.H. & H.	600 v. C.C. 6,000 v. A.C. 25 ~	250	—	—	—	flexible concentric drive	4' 8½"	62 in.	44	80*	—	—
	G.E. 84	G.E. Co.	N.Y. Central	600 v. C.C.	400	—	—	—	direct drive	"	44 in.		60-70	—	Two-pole direct drive motor-armature built on locomotive axle
		G.E. Co.	N.Y. Central	600 v. C.C.	250	188 h.p.	—	—	"	"	36 in.		60-70	—	Two-pole direct drive motor-armature built on locomotive axle
		Ganz	Valtellina	3-phase 3,000 v. 15 ~	400	—		—	Scotch yokes	"	1,500 mm.	37·5	40		Double motor for single and cascade working
		Brown Boveri	Simplon	"	850	—	—	—	coupling rod frames	"	1,250 mm.		—	12·25 tons	Four-speed squirrel-cage induction motor
		Westinghouse	Pennsylvania	600 v. C.C.	2,000	—	—	—	jack shaft & coupling rods	"	72 in.	45‡	60-70	19·2 tons	Weight includes armature shaft and cranks
		Thomson Houston	Midi	single-phase 12,000 v. 16⅔ ~		—	750	600 h.p.	"	"	1,310 mm.		48·5	—	1—C—1 locomotive
		A.E.G.	Lötschberg	single-phase 15,000 v. 15 ~	800		—		"	"	1,270 mm.	25	46·5	—	1 B + B—1 locomotive
	W.B.M. 1,700	Siemens	Wiesenthal	single-phase 10,000 v. 15 ~	525*	251 kw. at 270 volts †	—	—	"	"	1,200 mm.	43·5	43·5	9·2 tons	Final design 1—C—1 locomotive. Weight excludes armature shaft and bearings
	W.B.M. 1,500 s.	Siemens	Wiesenthal	"	525*	287 kw. at 250 volts †	—	—	"	"	1,050 mm.	—	43·5	9·17 tons	Experimental design 1—C—1 locomotive. Weight excludes armature shaft and bearings
	W.B.M. 2,700	Siemens	Dessau-Bitterfeld	single-phase 15,000 v. 16⅔ ~		—	—	574 kw. at 375 volts †	"	"	1,050 mm.	25	37·5	14·4 tons	0—D—0 locomotive. Weight excludes armature shaft and bearings
		A.E.G.	"	"		—	1,000	—	"	"	1,600 mm.	—	80	—	2—B—1 locomotive
	W.B.M. 2,800	Siemens	"	"	1,000*	—	—	583 kw. at 310 volts †	"	"	1,600 mm.	—	68	13·2 tons	2—B—1 locomotive. Weight excludes armature shaft and bearings
		Bergmann	"	"		—	1,500	—	"	"	1,600 mm.	—		15·5 tons	2—B 1 locomotive. Weight excludes armature shaft and bearings
	W.B.M. 2,700 s.	Siemens	"	"	1,250*	449 kw. at 310 volts †			"	"	1,150 mm.	43·5	52	13·06 tons	1 D 1 locomotive. Weight excludes armature shaft and bearings
	W.B.M. 4,200	Siemens	"	"		648 kw. at 350 volts †	1,800*	648 kw. at 350 volts †	"	"	1,600 mm.		68·5	18·065 tons	1 C 1, 1000 locomotive. Weight excludes armature shaft and bearings
	W.B.M. 3,700	Siemens	Kiruna-Riksgraensen	single-phase 15,000 v. 15 ~	—	—	1,250*	800 h.p.	"	"	1,100 mm.		37·5	13 tons	1 C + C—1 locomotive. Weight excludes armature shaft and bearings
		Brown Boveri	Milan Varese	650 v. C.C.			1,000	—	"	"	1,500 mm.	37·5	66	9·15 tons	1—C—1 locomotive. Weight includes armature shaft and bearings
		Brown Boveri	Simplon	3-phase 3,000 v. 15 ~	nom'l 450	575 h.p.	—	—	Scotch yokes	"	1,640 mm.	43·5	46	10·75 tons	Weight of two motors and two Scotch yokes, 21·5 tons
		Westinghouse	Giovi	"	—	—	1,000	—	Scotch yokes	"	1,070 mm.	27·5	28	—	—
		Bergmann	Silesian		—	—	—	2,500 h.p.	2 jack shafts	"	1,200 mm.	34‡	62	24 tons*	2—D—1 locomotive. Weight excludes armature shaft and bearings
	W.B.M. 3,700 s.	Siemens	Prussian State	single-phase 15,000 v. 16⅔ ~	—		—	769 kw. at 315 volts †	jack shaft	"	1,250 mm.	—	62	13·4 tons	1 C 1, 1250 locomotive. Weight excludes armature shaft and bearings

* Approximate. † Electrical input at continuous rating. ‡ At continuous rating.

veniently high for small motors. On the other hand there is no great difficulty in insulating master controllers and contactor-operating coils for 600 or 750 volts, or in reducing the voltage on each coil by means of control rheostats.

It would be a mistake, however, to press forward too much in the direction of a rigid standardization until the general requirements of electric locomotives and their operating conditions are better known. By that time it is possible that outstanding differences of opinions in regard to various questions of locomotive control may have been settled, and standardization may be taken in hand to the advantage of purchaser and manufacturer alike.

Discussion before The Institution on 26th February, 1914.

Mr. Smith. Mr. Roger T. Smith: In the author's exhaustive paper on "Electric Locomotives," published in Volume 51 of the *Journal*,* it is pointed out that in America electric locomotives were in the first place adopted for hauling very heavy loads either through tunnels or into termini with fairly dense traffic, while on the Continent their first use was for main-line work, chiefly on steep gradients and through tunnels, but with a comparatively sparse traffic. I would suggest—which I think the author's paper bears out—that the reason for this is largely due to the relative price of coal in America and in Europe. With coal at over 20s. per ton, and with water power available, as is the case in many countries in Central Europe, electric main-line working may be quite economical compared with steam working. The same remark applies to the Argentine Republic and other parts of South America. In the United States, however, with coal at from $2\frac{1}{2}$ to 3 dollars (10s. to 12s.) per ton, or in this country with coal at from 10s. to 14s. per ton, other reasons than economy in working, I think, lead to electrification. I want to emphasize the word "working," because the coal of course only affects the working costs. There may be, however, many other economies that result from electric traction. In the United States the smoke problem and the physical circumstances of the tunnels entering New York, and elsewhere, have very largely forced the terminal electrification of railways. In England this has not occurred. It must be quite understood that we are not discussing suburban traffic, carried on with multiple-unit-controlled motor-coach trains, but only traffic, either passenger or goods, which demands a locomotive for hauling purposes. I venture to suggest that the electric locomotive will be used in Great Britain for some time to come, not from the point of view of any economy of working, but to secure such economies as may result from circumstances under which the electric locomotive can do what the steam locomotive cannot do. Such conditions occur in a number of places where mineral traffic is carried down from the hinterland—if one may use this term in such a small country as ours—a few hundred feet above the level of the sea. Where mineral traffic is carried to the sea, oftens happens, when it comes to returning with the empties, that it is necessary to divide the train into two or more parts, taking half the empty train up first and then returning for the other half. For busy mineral and colliery districts of this character the electric locomotive is actually being made to-day, with a maximum speed of, say, 35 miles per hour, appreciably lighter for the same adhesive weight and with a less load per axle than the corresponding steam locomotive; and it can haul whole trains of empties up gradients of 1 in 100, and even of 1 in 50, after taking down fully loaded trains.

* *Journal I.E.E.*, vol. 51, p. 730, 1913.

I gather from the first part of Mr. Lydall's paper in Volume 51 of the *Journal* that it is easy enough to design an electric locomotive to deal with one class of traffic, but that the difficulties begin when several classes of traffic have to be dealt with by the same locomotive, and especially at several different speeds. For instance, on page 746 of that volume the author suggests a goods locomotive giving a pull of some 12 tons at 25 miles per hour. I should like to ask him if he contemplated doing this with continuous-current series motors. The output would be 2,000 h.p. at this pull and speed, and, if the adhesion allowed, could give a maximum starting pull of something like 30 tons. Now for nearly everything a locomotive of that power would have to do if equipped with series continuous-current motors, it would be running with the resistances in series, except when it had to pull its maximum load at almost the maximum or half the maximum speed. Another point as to which I should like to ask the author for information is this: I notice he implies that the difference between tractive effort and draw-bar effort is, in general, equivalent to about 700 lb. draw-bar pull. I would suggest that this is really somewhere about half what it ought to be. Little information has been published as far as I am aware on the tractive effort required to haul the locomotive itself. Experiments have been published with steam locomotives on the Orleans Railway, and taking those results as applicable to electric locomotives for such speeds as are dealt with in this paper, the resistance of the locomotive is something like 20 to 30 lb. per ton. If that figure is applicable it would mean that merely to haul the locomotive we should want a pull of about 1,500 lb. instead of about 700 lb. The author also suggested on page 747 of Volume 51 a passenger locomotive able to haul 200 tons up a gradient of 1 in 100 at 60 miles per hour. Now this is a draw-bar pull of just under 3 tons, and if the locomotive were fitted with continuous-current series motors it would give the maximum permissible draw-bar pull of 12 tons at nearly 40 miles per hour. For speeds below 40 miles per hour resistances would have to be used in series with the motors in order to prevent the wheels slipping. I would ask the author if he contemplated that this locomotive could be equipped with continuous-current motors.

He shows very clearly on page 749 (Volume 51) that economy in first cost depends on the highest permissible peripheral speed which can be given to the active material on the commutator, and that this speed is tied by the maximum permissible speed that can be given to the pitch line of the gearing. May I take it from what is inferred, though not perhaps directly stated, in the paper, that about 45 metres per second is the maximum armature peripheral speed which is allowable, while the maximum permissible speed of the pitch line of the gearing is about

Mr. Smith. 20 metres per second: I think the author makes out a case that for the higher speeds in electric locomotive working the use of gearing combined with couplings and connecting rods is a mistake because it leads to an uneconomically low peripheral speed of the motor armature; and that, for high speeds, gearless motors either with motor armatures concentric on the axles or with coupling and connecting rods must be used. This, however, seems to be modified by the experience quoted in the supplementary paper,* and I should like to know if the author's general conclusion now is that on the whole it is better to use gearing combined with coupling rods.

With regard to the paper on "Motor and Control Equipments for Electric Locomotives,"† the author shows very clearly the effect of adhesion in determining the control equipment for either continuous-current or alternating-current commutator-motor locomotives. He points out how the lower limit of current and hence of torque during the notching period when the locomotive and train are being accelerated up a gradient really determines the maximum weight of the train. This is most important, and although it should be quite obvious I have never seen it clearly stated before. Figs. 4, 5, and 7 will repay study by all engaged in this problem, and one cannot but be impressed in this connection with some of the advantages of the alternating-current commutator motor as compared with the continuous-current motor for slow hauling of heavy trains up grades. Not only does Fig. 7 show how with single-phase working the acceleration is obtained with one-third of the number of notches required for a continuous-current motor of about the same power, but the author very clearly shows that with continuous current, if the actual train load is too near the minimum torque exerted by the motors during the notching period, it may happen that the current on any notch does not decrease sufficiently to get on to the next notch without slipping the wheel. Should any slipping occur it may be necessary to stop and begin the acceleration all over again. With the alternating-current motor every notch is a running notch, and the driver can continue running on that notch without any waste of energy or overheating of resistances until the gradient conditions change and he can get on to the next notch.

The author's arrangement, described on page 390, for using his inductive regulator to raise the voltage gradually between one transformer tapping and the next, is ideal in theory, and I should very much like to ask if in practice the only trouble is the one to which he has referred, namely, the extraordinary fluctuations in torque on this induction regulator. As far as the design of electric locomotives has gone already, if the number of types for the various services is to be kept down, unless the Ward-Leonard or some equivalent system of voltage variation control is used, it seems to me that it will be very difficult for the continuous-current locomotive to meet the case. The difficulty of course occurs only during the accelerating period. If the author could say anything about the experience in that respect with Continental locomotives I should be glad. The difficulty of rheostatic control for varied conditions is a real one, for the author has pointed out the impossibility of designing the values of the resistances for continuous-current motors to meet all the varied conditions. Mr. Smith.

* See Vol. 52, p. 381.

† Page 384.

One other matter that the author brings out is the advantage of automatic control during the accelerating period. The predetermined lowest point to which the current should fall between one step and the next determines automatically when the controller passes on to the next notch, this being quite out of the control of the driver. It is rather curious, as the author points out, how little automatic notching has been used in this country; but on the North-Eastern Railway they use nothing else—the driver merely pulls his controller handle right round and the controller notches up automatically. The advantage of this was clearly shown in the late railway strike. During the strike the North-Eastern Railway Company's electric traction was satisfactorily maintained, because it was found possible to draft in men as drivers from the sub-stations and elsewhere who had a little knowledge of electricity. They had only to be taught all that was essential about the signals on the line, and as far as driving went they had merely to pull the controller handle right round and the automatic arrangements did the rest.

Mr. F. W. CARTER: Referring particularly to the author's paper that was published in Volume 51 of the *Journal*, it appears to me that though it has much to commend it, it suffers from a serious defect, namely, that it is not critical enough, and even where it is slightly critical it is apt to be a little partial. We are at present in the early stages of the art of electric locomotive design, and it is quite inevitable that a number of unsatisfactory forms should be developed which will not be heard of in a few years' time. There is not necessarily any discredit to the makers in this, for they are simply gaining experience which will enable them to evolve the satisfactory types. One would, however, expect the author of a paper on the subject to do something to compare the different forms, and point out the weaknesses and objections to each. Mr. Lydall's paper gives such particulars of various types as the manufacturers supply to the technical press, and would lead one to suppose that types are more or less equal to one another in desirability, and that the construction that settles which type is most desirable is the peripheral speed of the motors, or something of that nature. Actually, many of the types that the author describes have given a great deal of trouble, and are open to grave objections. As an instance, I may refer to his Fig. 13 [Vol. 51, facing page 752], which shows a locomotive with three coupled wheels, two jack shafts, and outwardly sloping connecting rods, the motors being under the sloping ends of the locomotive cab. I believe a diagram of the same locomotive was introduced in Messrs. Storer and Eaton's paper on electric locomotives read before the American Institute of Electrical Engineers in June, 1910,* and there it appears to be used by way of an example of what a locomotive should not be, the objection to it being that the large masses of the motors at the ends of the locomotive give it a large moment of inertia about the vertical—this has always been recognized as causing nosing, and tending to spread the rails at the entrance to curves if it is run at any consider- Mr. Carter.

* N. W. STORER and G. M. EATON. "The Design of the Electric Locomotive." *Transactions of the American Institute of Electrical Engineers*, vol. 29, p. 1415, 1910

Carter able speed. Mr. Lydall says of this locomotive: "Ten locomotives were ordered, but the one shown in Fig. 13 was built first in order that the design might be thoroughly tested before the others were put in hand. The tests were carried out on the electrified line between Dessau and Bitterfeld with very good results. The remaining nine locomotives are now being built to a slightly modified design referred to below, and shown in Fig. 21." I have been long enough with a manufacturing company to recognize this statement as the manufacturer's way of expressing somewhat the same opinion as Messrs. Storer and Eaton, for Fig. 21 is a totally different design, in which the two motors have been brought together at the centre of the locomotive. I gather, however, from Mr. Lydall's supplementary remarks that the modified type has also proved unsuccessful.

As another instance, I may refer to the Lötschberg locomotive [shown in Mr. Lydall's Fig. 14], which was in fact supplied on approbation by a German firm to the Lötschberg Railway, and after having been thoroughly tried, was rejected. I think we may assume that this was not on account of its having been found satisfactory and suitable for its work. In order that it may be clear that I am not alone in considering that some of the types that Mr. Lydall has described are thoroughly unsatisfactory, and that the troubles that have occurred in connection with them are fairly well known, I will give extracts from an article by Mr. R. E. Hellmund, a well-known American authority on the subject, which appeared in the *Electric Journal* for last October.* Mr. Hellmund says: † "The mechanical design of the locomotives at Dessau–Bitterfeld cannot, in general, be considered very successful. Several reasons seem to be responsible for this. First, the Government practically dictated the policy of using one or two very large motors per locomotive and side-rod drive, and eliminated schemes for applying gears together, thereby limiting the possibilities to a design which brings with it a number of inherent difficulties." Referring to a passenger type of locomotive with vertical side rods, Mr. Hellmund says: † "Most of these locomotives have only one large motor. Only one locomotive which was originally built by the A.E.G. for the Lötschberg electrification [Mr. Lydall's Fig. 14], and was there rejected on account of not meeting requirements, and subsequently bought by the Prussian Government, has two motors and practically vertical side rods. All these locomotives with one big motor [shown in Mr. Lydall's Fig. 17] have sooner or later given trouble, due to the breaking of the cranks and crank pins. The mechanical parts have since been strengthened considerably, but have not been in service long enough to show that they are now sufficient to do the work." Referring to a freight locomotive with four drivers and a jack shaft, driven by one big motor by means of side rods inclined about 45 degrees [shown in Mr. Lydall's Fig. 18] Mr. Hellmund remarks, "These locomotives have so far given best satisfaction in service, although they are subject to rather pronounced vibrations. There is little doubt, however, that some type of geared locomotive would have been a better solution for this service." Of a third type he says,* "Quite recently a number Mr. Carter. of locomotives of a heavier type have been tried. These locomotives have two large motors, driving a common jack-shaft by a side rod inclined about 45 degrees [this is shown in Mr. Lydall's Fig. 19]. This design seems to be altogether a failure. One locomotive was tried on experimental runs, and began to vibrate very severely at a speed of about 40 miles per hour. Subsequently, there was a big noise followed by smooth running. After the locomotive had been brought to rest, it was found that the crank pin of the jack shaft was missing. A second locomotive of the same type behaved quite similarly, with the exception that the crank pin of the jack shaft and both of the inclined side rods were broken." In his general summary of the subject, Mr. Hellmund says,† "The only European locomotives that have been successful from a mechanical point of view, and which give at the same time reasonable weights, use either gear arrangements or the Scotch yoke construction, or both, and even in Germany it seems that the gear arrangement will be used in spite of much opposition." This is a Westinghouse view, and I think in the main a sound one.

There are very good reasons which render the side-rod type of locomotive a very difficult one to make satisfactorily; reasons, in fact, sufficiently strong to proclaim this a type to be avoided wherever practicable. For one thing very fine adjustment is required, without which the case would be hopeless; much more difficult mechanical fitting is necessary than anything connected with the steam locomotive. The chief trouble is that the uniform torque of a motor can only be converted into a pair of reciprocating forces in the direction of the side rods by subjecting the frame of the locomotive to very severe stresses.

If T is the maximum tension in a connecting rod, and θ is the angle of the crank measured from the line of centres, the tension in the connecting rod is $T \sin \theta$, and that in the connecting rod on the other side of the locomotive, where the crank is at right angles, is $T \cos \theta$. These forces can be written—

$$T \sin \theta = \frac{T}{\sqrt{2}}\left[\sin\left(\theta + \frac{\pi}{4}\right) + \sin\left(\theta - \frac{\pi}{4}\right)\right]$$

$$T \cos \theta = \frac{T}{\sqrt{2}}\left[\sin\left(\theta + \frac{\pi}{4}\right) - \sin\left(\theta - \frac{\pi}{4}\right)\right]$$

Thus the forces exerted by the connecting rods, besides balancing the torque of the motor, impose on the locomotive frame a system of forces composed of a reciprocating force of maximum value $T\sqrt{2}$ in the direction of the connecting rods and an alternating couple of maximum turning moment $Ta/\sqrt{2}$ in the plane of the coupled axles, where a is the horizontal distance between the connecting rods. The couple is the troublesome element, as it is of large magnitude. If b is the length of the crank, Tb will be the torque of the motor, so that the ratio of the turning moment of the couple to the torque of the motor is $a/b\sqrt{2}$. For a full gauge locomotive, a is of the order of 80 in., and b of the order of 8 in., so that the above ratio is about 7, *i.e.* the turning moment of the couple is about seven times the torque of the motor.

* R. E. HELLMUND. "Electrification of Trunk Lines in Europe." *Electric Journal*, vol. 10, p. 981, 1913.
† Page 982.

* Page 983. † Page 997.

Mr. Carter. Mr. Lydall, in Table II on page 755 (Vol. 51), gives the torque of a few motors, one of which is as much as 30,000 lb. at one foot radius. This is at the rated load and is not an exceptionally high figure. The turning moment of the couple discussed is about seven times this, and is therefore close on 100 tons at a foot radius. This figure, however, is an average, and these locomotives are practically all single-phase, so that the maximum value of the torque is twice the average; thus the maximum turning moment of this couple is of the order of 200 tons at one foot radius without any allowance for overloads, or for inertia effects, which may very materially increase the couple. A racking stress of this nature is very severe on the locomotive structure, so that even if no extra stresses are introduced by inaccuracy of workmanship, and these are very difficult to avoid where such close fitting is necessary, it will be seen to be no small problem to make the frame sufficiently rigid. No such stresses occur in the steam locomotive, for in the first place the driving force is applied in a reciprocating manner, and in the second place it is applied from two points not distant from the two points where it is used. It is the designer's business to arrange that the force exerted on each side of the locomotive is about equal to the force used on that side, so that there are no large forces applied on one side of the locomotive and used on the other. At a jack shaft the conditions are likely to be even worse than at the motor shaft, for here the connecting rod and coupling rod meet at an angle, and the effect on the locomotive frame is resolvable into a force the direction of which rotates round the jack shaft in the opposite direction to the crank, and a couple the axis of which rotates in a similar manner. If α is the angle between the connecting rod and the coupling rod, the value of the force is $T\sqrt{2}\sin\alpha$ and the moment of the couple is $T\,a\sin\alpha/\sqrt{2}$. When the connecting rod and the coupling rod are at right angles (as in Mr. Lydall's Fig. 17) the values of the force and the moment of the couple are at their greatest, and are then equal to $T\sqrt{2}$ and $T\,a/\sqrt{2}$ respectively. The turning moment of the couple is therefore, as before, of the order of seven times the torque of the motor. This is a more difficult condition to meet than that at the motor-shaft; for with the couple in one plane, rigidity has only to be provided in that plane, whilst with a couple whose axis is rotating, rigidity must be provided in all planes. It is therefore not surprising that locomotives of this type have given a great deal of trouble; for if these large stresses are able to produce any appreciable distortion, binding is almost inevitable somewhere, and the stresses become applied at points which cannot possibly be made strong enough to resist them.

Mr. Bowden. Mr. J. Bowden: In this paper attention is first directed to the limitations of gauge, and electric locomotive engineers are confronted with the restrictions which, had Brunel's gauge policy triumphed, would not prevail on the roads of to-day with their heavy traffic. Apart from the question of electrical design, these limitations impose mechanical difficulties which may ultimately prove more serious than with steam locomotives. The heaviest maintenance expenses in electric traction may very easily be incurred on locomotives and rolling stock, and these are almost wholly governed by the mechanical design. Gears and bearings may seriously affect the maintenance cost, not by fracture and wear alone, but by the expense incidental to failure in service, such as the loss of armature shafts and partial loss of tyres, owing to the necessity of clearing any obstruction to a closely timed train schedule with the least possible delay. With motors pressed to the duty imposed by the requirements of many suburban services, adequate mechanical design is difficult when gears are employed, and other ways of securing a reliable and economic transmission from motor to driving wheel have been sought. One alternative is illustrated in Mr. Lydall's paper by the 2,000-h.p. 600-volt continuous-current motors of which the mechanical arrangement has been designed by Mr. Gibb of the Pennsylvania Railroad. In this design a steam locomotive engineer of wide experience has adopted connecting and side rods of simple construction working from a jack shaft. Mr. Carter has indicated the weak points of such a design, which involves mechanical problems not met with in steam locomotive design. Another alternative used by the New York Central Railroad carries the armatures on the axles, eliminates gears, and obtains a simple yet substantial construction which has much to recommend it. Doubtless, difficulties arise in the electrical design, and the unsprung axle loads may not in some instances be permissible, but on the point of maintenance, experience of those who have operated this design is particularly favourable. Under the heading of control the paper deals at some length with the arrangement of resistances, having particular regard to shocks during starting. The largest electric locomotives in this country to-day were designed by Mr. C. Jones of the Metropolitan Railway Company. The gradations of resistance are there adjusted by trial and correction of error with satisfactory results. Automatic control is largely used by the Metropolitan Railway Company with excellent results on multiple-unit trains, but it has not yet been applied to electric locomotives.

The conditions of long-distance suburban trains making frequent stops near the central terminus and running as express trains when far out, call for special consideration. The combination of at first high acceleration and then high average speed over a longer distance will have to be more generally provided for as electrically-worked suburban services are developed. Some additional means of control is necessary, and perhaps the author will say whether field regulation has been successfully used in this direction.

Contactor reversers are mentioned in the paper. The drum reverser has not been very satisfactory, particularly where accelerated service has rendered necessary the frequent overloading of equipments. The objection to maintaining an increased number of contactors is not very serious if greater reliability and less burning of reversers can be secured. Low maintenance cost of contactors does not so much depend upon their number as upon confining the destructive opening of circuits to a few contactors. With regard to motor-generator control as outlined in the paper, perhaps the author will say whether this has yet been applied to electric locomotives, and if so with what success.

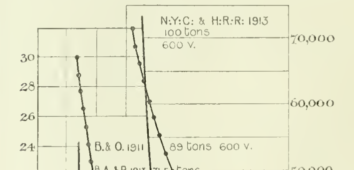
Mr. Sparks. Mr. J. B. Sparks: Mr. Stevens has asked me to show some slides which he prepared especially for this discussion and would have shown this evening had he been able to be present. They give the general design and the dimensions of the Baltimore and Ohio, New York Central,

arks. and Butte and Anaconda locomotives, and also some views of the last-mentioned locomotive.

With regard to Mr. Lydall's paper, I should like to call attention to his statement that, owing to the requirements of single-phase motor design, the voltage even at full speed is seldom more than about 300. At this pressure, assuming a power factor of 0·83, the single 1,800-h.p. motor of the 1—C—1 Siemens Schuckert locomotive takes a current of 6,000 amperes. Now a corresponding continuous-current motor with 1,200 volts across the commutator would take only one-fifth of that, viz. 1,200 amperes, so that, although in the continuous-current control it may be necessary to have a larger number of contactors, the fact that only one-fifth of the current has to be handled may make the continuous-current control gear both cheaper and less bulky. With a pressure of 2,400 volts across the commutator, which is quite practicable for a large motor situated in the cab of the locomotive, the current to be handled would be only one-tenth of the corresponding current for the single-phase motor. The effect of this heavy current on the design of the transformers, control gear, and motors, is probably one reason why single-phase locomotives are so much more expensive than continuous-current locomotives. Mr. Roger Smith in his paper mentioned £50 per ton as a figure to be aimed at. The cost of continuous-current locomotives is already only £60 or £70 per ton: for example, the average cost of the 47 locomotives of the New York Central Railroad works out at just over £7,000, which represents a little more than £60 per ton. Very few figures have been published for single-phase locomotives, but the cost is approximately double that of continuous-current locomotives. For example, the 800 h.p. 53-ton locomotives for the Mittelwald Railway, referred to by Mr. Lydall this evening, cost nearly £6,000 each, or £112 per ton. The price per horse-power appears to be £5 or £6 in the case of the continuous-current locomotives, and from £7 to £10 per horse-power for the single-phase locomotives. The figures vary, of course, within very wide limits, but the above are representative of the costs that I have been able to obtain.

nith. Dr. S. P. Smith: I agree with Mr. Carter's criticism of the paper, for I think the author deals far too favourably with many points; for example, the 1—C—1 locomotives for the Wiesenthal line, referred to by Mr. Carter. After the experimental locomotive gave "very good results" the remaining nine were "built to a slightly modified design," consisting of an entire redistribution of the load, with the result that they rattled. In consequence all nine locomotives have had to be altered again, but unfortunately the author is unable to tell us the nature of the alteration that has made them a success. However, at this late hour I only propose to discuss the comparison on page 386 between the motor for the continuous-current Pennsylvania locomotive and the single-phase motor for the 1—B + B—1 locomotive. In the first place, 2,000 h.p. is the short-period rating of the continuous-current motor, and not the one-hour rating at all—I believe it is really a 1,200-h.p. motor—whilst the so-called Lötschberg locomotive is, I think, running between Dessau and Bitterfeld. The comparison between these two motors is very unfair for the following reasons: Though the pressure on the continuous-current motor in this instance is only 600 volts, the standard pressure for such outputs would be 1,200 or 2,400 volts. When we consider a high-tension continuous-current motor the problem is quite different, and a much heavier motor is obtained. As it is, the author tells us that the motor weighed 19 tons. It would weigh much more if it were a high-tension motor. The 800-h.p. single-phase motor weighs, I believe, 14 tons, and is of the repulsion type with phase compensation. I pointed out some time ago * that this particular motor was about the most unfavourable type with respect to weight and speed that could be obtained for single-phase working. If the comparison had been with the compensated series motor, it would have been much more favourable. But even as it is I think we have an 800-h.p. alternating-current motor weighing 14 tons and a 1,200-h.p. continuous-current motor weighing 19 tons. Moreover, from the table given on page 397 I find that the continuous-current motor runs at 210 r.p.m. and the other motor at 168 r.p.m., a difference of about 25 per cent; though from an article in the *Electric Journal* of 1910 I think the speed of the continuous-current motor should be 280 r.p.m. Thus the comparison is very misleading. A fair comparison would show—what many designers have found out—that a large high-tension continuous-current motor weighs approximately about the same as the corresponding single-phase commutator motor. Dr. Smith.

Mr. T. Stevens (*communicated*): I have obtained, by the courtesy of the manufacturers, some data on a few Mr. Stevens.



* S. P. Smith. "The Use of Single-phase Commutator Motors for Electric Traction on Long-distance Railways." *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 190, p. 310, 1911–12.

Mr. Stevens.

TABLE.

Reference Number of Columns	24	25	26	27	28
Name of railway	Butte Anaconda and Pacific		Baltimore and Ohio	New York Central and Hudson River	
Symbol	0—4—4—0		0—4—4—0	4—4—4—4	
Type	2 articulated bogies		2 articulated bogies	4 bogies	
Number of driven axles	4		4	8	
Gauge	4 ft. 8½ in.		4 ft. 8½ in.	4 ft. 8½ in.	
Length inside knuckles	37 „ 4 „		39 „ 6 „	55 ft. 2 in.	56 ft. 10 in.
Height trolley down	15 „ 6 „		12 ft. 4 in. no trolley	14 ft. 5¾ in.	
Overall width	10 „ 0 „		10 ft. 2½ in.	10 ft. 0 in.	10 ft. 0 in.
Weight on driving axles (tons, 2,240 lb.)	71·5		89	100	112
Weight on pony axles (tons, 2,240 lb.)	nil		nil	nil	
Total weight ... ... (tons)	71·5		89	100	112
Fixed wheel-base	8 ft. 8 in.		9 ft. 6 in.	5 ft. 0 in. and 6 ft. 6 in.	
Diameter of driving wheels	46 „		50 „	36 in.	
Distribution voltage	1200/2400		600	600	
Frequency	C.C.		C.C.	C.C.	
Number of motors	4		4	8	
Type of motor	series		series	series	
Rated h.p. per motor	280		280	292	330
Transmission	single gear		single gear	(direct)	
Gear ratio	4·83	3·2	3·25	bipolar motors	
Type of gearing	straight		straight	gearless	
Tractive effort of all motors, one-hour rating ... ... (lb.)	26,000	17,500	25,000	17,200	20,400
Tractive effort at 25 per cent adhesion	40,000		50,000	56,000	62,500
Speed at one-hour rating (m.p.h.)	16	24	16·4	51	48·5
Control system	type M		type M	type M	
Weight of electrical equipment (tons)	26·8		29	33	39·4
Date of setting to work	1913		1911	1913	1914
Number of locomotives	15	2	2	10	6
Service	goods	passenger	goods	passenger	

quite recent locomotives not included in the author's Table I.* He gave data for 23 locomotive designs, and to avoid confusion I have used as reference numbers, 24 to 28 inclusive. I note that in his Supplementary Paper † the author gives an outline of a New York Central locomotive (1914 type); columns 27 and 28 in the table herewith relate to the New York Central locomotives of the 1913 and 1914 types, and I leave this in the form in which I had prepared it before Mr. Lydall's Supplementary Paper was published. I also note that he gives the diameter of the Butte Anaconda driving wheels as 48 in. I have checked the dimension on the manufacturer's data sheet, which gives it as 46 in.; Mr. Lydall, however, may have later information. The Butte Anaconda locomotives are interesting as being the first to take their supply from contact wires at 2,400 volts. The slides, which were kindly shown by Mr. J. B. Sparks in my unavoidable absence, included a drawing showing the dimensions of the 17 locomotives on this line, photographs showing the side and top of the locomotive with the insulated busbar line for coupling two locomotives to take power from one collector, a photograph of a train in service (this being a mineral service, as far as 15 locomotives are concerned, and passenger service operated by two locomotives which, as will be seen from column 25 of the table herewith, have a gear ratio of 3·2 and a speed of 24 miles per hour. In other respects the goods and passenger locomotives are alike). The photograph shows the nature of the country through which this line runs; and, as pointed out in my paper entitled "1,200-Volt Traction in the United States of America,"* there is no necessity in such a place for limiting the pressure-drop in the rails to such a small figure as is reasonable under Board of Trade Regulations, where previous interests have installed pipes that might be injuriously affected if the pressure-drop were high. The Board of Trade has under similar circumstances in this country been willing to extend the specified limit of voltage-drop in earthed returns in places where no pipes exist. A view was also given of the overhead construction on the Butte line, showing the wooden supports along the railway and the iron frames which carry the overhead wires across a bridge. The curves on page 402 show the tractive effort and speed of the Baltimore and Ohio 1911-type locomotive, and of the Butte Anaconda and New York Central 1913-type loco-

* *Journal I.E.E.*, vol. 51, facing p. 752, 1913.
† Vol. 52, p. 381.

* *Journal I.E.E.*, vol. 48, p. 890, 1912.

Mr. Stevens. motives in full lines, indicating the one-hour rating on the standard basis, but it should be remembered that these motors have forced ventilation. In this diagram the Pennsylvania locomotive curve and the 2,500-h.p. curve in Mr. Roger Smith's paper* are reproduced, and in addition a 6,000-h.p. curve is shown, which crosses the New York Central curve at 28 tons' tractive effort.

The General Electric Company of New York supplied the locomotives referred to in columns Nos. 24–28 of the table, and my acknowledgments are due to them for the data from which the curves and table have been prepared.

Mr. O'Brien. Mr. E. O'BRIEN (*communicated*): Speaking from a railway point of view it is very desirable that the control of any locomotive should be entirely by contactors, and that the contactors should be placed in such a manner that any disturbances taking place in them cannot affect the driver. The cab should be kept entirely free from apparatus that is more than two or three feet above the floor level, so as to enable the driver to have a completely free look-out all round him. The geared-motor bogie type of electric locomotive is undoubtedly the most suitable type for railway purposes and the one most likely to result in low maintenance costs. The sole objection to it appears to be the low centre of gravity of the bogies and their moment of inertia around their centres, both of which tend to have a destructive action on the track and affect the riding. In an electric bogie locomotive, therefore, there appears to be no reason why the centre of gravity of the motor should not be placed vertically above the centre of the axle, thus raising the centre of gravity to a reasonable extent. The paper as a whole will draw the attention of railway men to the extreme complexity and inflexibility of the electric locomotive, and will confirm them in their opinion that though it may render admirable service under special conditions, it is not suitable for general service. The attention of electric locomotive designers should be drawn to the extreme noisiness of all existing locomotives—steam or electric—as far as those riding in them are concerned, and endeavours should be made to damp out the vibrations which tend to make the cabs act like sounding boards.

* *Journal I.E.E.*, vol. 52, p. 297, 1914.

Mr. LYDALL's reply to the discussion will be published in a later issue.

THE GULSTAD VIBRATING RELAY.

By W. JUDD, Member.

(*Paper received 3rd March, 1914.*)

In this description of the Gulstad Vibrating Relay the object is to bring to general notice this remarkably ingenious and efficient piece of telegraph apparatus.

Devised by Mr. K. Gulstad, sometime Engineer-in-Chief to the Great Northern Telegraph Company of Copenhagen, and given freely to the world by means of descriptions in the *Electrical Review* of June, 1898,* and August, 1902,† it has been in use by that company for over 20 years, and in more recent years by other telegraph administrations to a small extent.

This relay, while being several times as sensitive as the ordinary polarized relay, is at the same time much more stable in the presence of disturbances from neighbouring lines, or from a defective duplex balance. These most important and valuable features consequently give a higher speed and more stable signals than any other polarized relay known to the writer.

It is only applicable to double-current Morse signalling, and is efficient on all land lines and on submarine cables having a KR of from 0·5 to 0·75 second. On a cable having a KR of 1 second it will give very fair results, but that is rather beyond the safe limit.

The somewhat remarkable combination of increased sensibility to signals and increased stability against disturbances, appears to be explained by a consideration of the vibratory circuits. Premising that no line current is present, it will be seen that when the tongue of the relay comes in contact with one or other stop, a condenser is charged through one relay auxiliary winding pressing the tongue momentarily on this stop. Then, the condenser being charged, the current rises in the opposite auxiliary winding, through an external resistance, and pulls the tongue off, when the discharge current from the condenser flowing through both auxiliary windings throws it vigorously over on to the other stop. The same cycle of operations is then repeated with opposite polarity of the battery. In this manner a continuous and regular vibration of the armature and tongue is set up, with contacts firmly made and cleanly broken.

The speed of these vibrations must be made equal (or nearly equal) to the pre-arranged speed of dot signals from the line to which the relay is applied, by suitable adjustment of the values of capacity and resistance in the local circuit, and the rate of rise of the local current also must be made to correspond with that of the cable current.

When these conditions are fulfilled, the only duty left for the cable current is to control the vibrations. This control is obtained by furnishing the electromagnets of the

* *Electrical Review*, vol. 42, pp. 751 and 792, 1898.
† *Ibid.*, vol. 51, pp. 294 and 332, 1902.

relay with a separate winding through which the signals received from the cable pass.

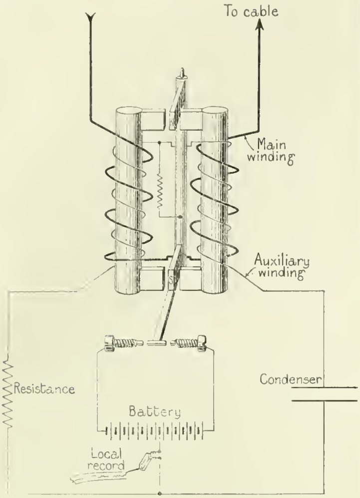


FIG. 1.

The heavier currents in this "main" winding, *i.e.* the cable "dash" or "space" signals, overpower the local vibrations, and hold the tongue on one or other stop below that of the local current by an amount giving a preponderance to the latter. The armature is then surrendered to the local forces, is pulled off, and is driven vigorously over to the opposite contact by the discharge from the condenser.

When "dots" are received from the cable their current amplitude is so small that only a very slight control, and in some cases practically none at all, is exerted over the tongue.

If the cable to which the relay is applied is a short one, the dots may control the tongue's vibration to the extent of accelerating or retarding its natural rate, thereby tending to correct any difference of phase between the impulses of the cable dots and the relay vibrations. In working through a moderately long cable, however, the current amplitude of dots at the receiving end would not have any appreciable influence upon the vibrations, and only the heavier dash and space currents would control the relay, which, however, would still reproduce the dots perfectly, by reason of the continuation of the local vibrations during periods when no controlling force is present in the main winding to check them.

Briefly stated, the resultant effect of the controlling cable currents and the local currents in the relay is this: that where dots received from the cable are to be reproduced, the vibrations are allowed to continue, and where dashes or spaces occur, the vibrations are damped out; and the short and long contacts of the tongue thus obtained are registered on the local recording instrument with all the increased firmness and definition supplied by the local forces.

With the Gulstad relay the cable current is relieved of the work of moving the armature and of overcoming the magnetic inertia which falls upon it with an ordinary polarized relay; great sensitiveness is thus attained. The instrument is also very adaptable to signals of varying character or of distorted formation, by reason of the elasticity of the electrical combinations in the local circuit.

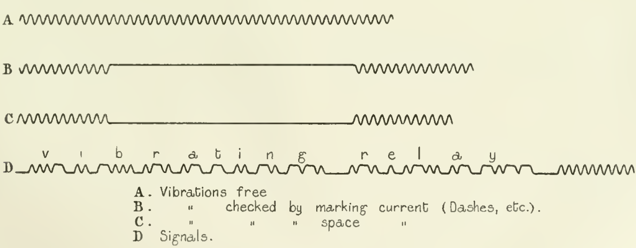


FIG. 2.—Signals registered on Local Record.

according to their polarity, until such time that the dash or space being completed at the distant end of the line the strength of the cable current at the receiving end falls

The accompanying diagrams, Figs. 1 and 2, illustrate the relation of the relay to its auxiliaries and show an example of the signals produced by it on the recording instrument.

THE "CASCADE" INDUCTION MOTOR.

By L. J. Hunt, Member.

(*Paper received 15th January*, 1914; *read before the* Manchester Local Section, 10*th February, and before the* Yorkshire Local Section, 11*th February*, 1914.)

In 1907 the author read a paper on this subject before the Manchester Local Section of this Institution* when the motor was in its early stages of development. Since that time large numbers of these machines have been built and numerous new windings have been worked out and tried, with the result that the modern machines differ materially from those described in the paper to which reference has been made.

The works of Messrs. Sandycroft, Limited, where these machines have been developed, are largely devoted to the manufacture of mining machinery, and when the building of induction motors was commenced it was soon realized that the short-circuited-rotor type of machine without slip-rings and with a low-voltage rotor was the ideal construction for withstanding the rough handling and onerous conditions to which mining machinery is habitually subjected. The squirrel-cage motor met these conditions for all drives where constant speed was required and where a moderate starting torque sufficed; but its sphere of usefulness was distinctly limited, and any attempt to extend it led to trouble. What was required was a short-circuited-rotor type of machine with the same characteristics as those possessed by the slip-ring motor, and after several futile attempts at solving the problem the use of the "cascade" principle was investigated. It was not long before it was found that other investigators had followed the same line of thought, the earliest being Dr. Silvanus Thompson, who patented a single "cascade" motor in 1901.

In order to explain clearly the windings used in the cascade machine, this paper describes the step-by-step development of the motors, for it has been found that by treating the subject in this way a clearer understanding of them is obtained. A very large number of windings have been experimented with, and reference to a few of them, with the reason why they have not been used commercially, may be of interest.

General Principles.

The application of the "cascade" idea is well known, as it has been used for many years in the control of three-phase locomotives, for obtaining several speeds in rolling-mill work, and for the driving of fans, etc. It is almost exactly analogous to the coupling of two or more motors in series on a continuous-current circuit. If two similar continuous-current motors be connected in series, with their shafts mechanically coupled, the speed of the combination will be half that of either motor directly connected to the line. Next consider one of the motors wound for a speed of 1,500 r.p.m. and the other for 750 r.p.m., with a pressure of say 300 volts across the terminals and the two machines in series. As the horse-power is proportional to the back electromotive force and the current in the armature, the low-speed motor will develop two-thirds, and the high-speed motor one-third of the total horse-power developed by the combination. It will be obvious that for any given speed the back electromotive force generated by the low-speed motor will be equal to twice that generated by the high-speed motor, and therefore the back electromotive force of the two machines in series will be equal to three times that generated by the high-speed motor alone. The set will therefore run at one-third the speed of the 1,500-r.p.m. machine, or two-thirds of that of the 750-r.p.m. motor, *i.e.* 500 r.p.m.

In the case of two induction motors wound for speeds of 1,500 and 750 r.p.m. the speed of the two coupled in series or "cascade" will similarly be 500 r.p.m. In this case the secondary of the first machine is connected in series with the primary of the second machine, and therefore as the same currents circulate in both the frequency must be the same. As in the case of the continuous-current machines, the low-speed motor will develop two-thirds of the total torque. In an actual case the pressure-drop due to resistance in the first motor slightly affects this proportion. If the rotor of the first machine is connected to the stator of the second machine, the windings must produce a flux in both stators revolving in the direction of the mechanical rotation. At 500 r.p.m. the slip of the first motor will be 250 r.p.m. if the low-speed motor is connected to the mains. This motor will have 8 poles if wound for a 50-cycle circuit. The second motor will have 4 poles, and consequently the speed of its stator field will be equal to twice the speed of the slip of the first motor, or 500 r.p.m. It follows that the frequency of the currents in the second rotor will be zero—the condition for synchronous speed.

Let P_1 and P_2 be the two numbers of pairs of poles for which the motors are wound, R the mechanical speed of rotation of the rotor in revs. per second, and N the frequency of the supply circuit. The frequency of the rotor currents will be—

$$N\left(1-\frac{P_1 R}{N}\right)$$

and the speed of the second stator field in revs. per second is

$$\frac{N(1-P_1 R/N)}{P_2}.$$

At synchronous speed there must be no relative difference in speed between this field and the mechanical speed of the second rotor, so that

$$\frac{N-P_1 R}{P_2}=R,$$

$$\therefore R=\frac{N}{P_1+P_2}.$$

* *Journal I.E.E.*, vol. 39, p. 648, 1907.

In other words the speed of the combination is equal to that of a motor wound for the sum of the numbers of poles of the two machines.

If the second stator winding had been so connected that its field had rotated in the opposite direction the speed would equal

$$\frac{N}{P_1 - P_2}.$$

This arrangement is not, however, of much commercial value.

At the synchronous speed of an induction motor no energy is transmitted to the rotor, and if we assume that the distribution of flux follows a sine law there will be no currents in the secondary windings. If, then, the mains are connected to the rotor of a machine the latter will revolve in a direction opposite to that of its magnetic field, so that at synchronous speed the field will be stationary in space and no electromotive force will be generated in the stator windings which now form the secondary of the motor. Instead of connecting the rotor windings of the first motor to the stator windings of the second machine, we may connect them to the second rotor windings, taking care to reverse two of the connections so that with currents circulating in both windings the magnetic fields produced will rotate in opposite directions. The stator winding of the second motor now becomes the secondary, and the rotor windings may be permanently connected without slip-rings. Control of the speed and starting torque is obtained by connecting resistances to the stator windings of the second machine. Here, then, we have a combination of two motors forming a single unit with their rotor windings permanently connected, and as no currents are brought out from the rotors the windings may consist of several parallel circuits, so that the voltages in them will be quite low even when the rotors are standing. This construction meets the requirements of a machine with a rotor winding approximating to that of a squirrel-cage machine, and with the same facilities for control of the starting torque and speed that can be obtained with a machine with wound rotor and slip-rings. We have, however, sacrificed much in obtaining these results. The necessity of using two machines leads to a greatly increased cost; and, further, the efficiency and power factor will be low, so that the construction is of little practical value. It was, however, the fundamental idea from which the motors described in this paper were developed, and will serve as a key to the explanation of their windings and properties.

There are examples of "cascade" coupling in nearly every power plant in the country. We install a step-up transformer in a power house and a step-down transformer in a sub-station; these are coupled in cascade and exactly represent a cascade motor at standstill. The energy current taken from the mains by the first transformer is dependent on the resistance (or load) connected to the secondary windings of the second transformer, and the first transformer takes from the line not only its own magnetizing current but also that required by the second transformer. In fact the calculations necessary for determining the currents in the windings, the power factor, etc., are identical in both cases.

To designers and engineers well versed in the design of induction motors all this will be very elementary, but as it has often been said of previous descriptions of these motors that too much has been taken for granted, an endeavour has been made in the present instance to atone for these shortcomings.

The next step in the development of the motor was to make a single stator and rotor which would take the place of the two separate machines. The problem to be solved was so to arrange the two sets of windings that there should be no mutual interaction, electrically or magnetically, between them, except by the agency of the interconnected rotor windings. It is interesting to glance at the various solutions of the problem arrived at by different investigators.

The stator of Dr. Silvanus Thompson's machine, to which reference has already been made, carried two sets of windings arranged in alternate segments of the circumference. If these segments be numbered 1, 2, 3, etc., the windings occupying all the odd-numbered segments were connected to form one winding and those occupying the even-numbered segments were similarly connected to form a second winding. One winding formed the primary and was connected to the mains; the other, which was unaffected by currents in the first winding, carried currents generated by a second rotor field and served as the secondary of the second element of the motor. The rotor carried a wave winding which was acted upon inductively by the primary stator field. The currents circulating in this winding also produced a second field, which in its turn acted inductively upon the secondary windings of the stator. Other inventors used the same type of stator windings with variations in the form of the rotor windings.

A German patent by Mr. G. Meller discloses another solution of the problem. In this motor there are two stators with windings carried in radial slots, and the rotor is in the form of a disc. One stator carries the primary windings and the other the secondary windings, the two being put in cascade by the windings carried on the single rotor.

Mr. F. Lydall's method of rendering the two sets of windings independent was to wind them for dissimilar numbers of poles, the numbers being so chosen that neither winding would act inductively upon the other. With this arrangement it was no longer necessary to confine each winding to certain parts of the stator, and all that was required was to provide two independent windings of ordinary construction placed one behind the other in the stator and rotor slots. This motor was patented in 1902.

Reference has been made to only a few typical examples of motors which have been developed, and these simply illustrate the methods suggested for obviating the necessity of two core bodies.

The first motor built at Sandycroft in 1905 was identical with Mr. Lydall's machine, the existence of which was unknown to the author until some time later. Tests made on this motor were satisfactory in so far as they showed that it was possible to construct a single cascade motor; but it was at once apparent that the electrical properties were inherently bad owing to the large losses in the two sets of windings and the necessity for the use of deep slots which caused the magnetic leakage to be very high. Electrically and magnetically the motor described later is identical with this machine, but new types of windings

are used in it which overcome the bad features of the original design.

Possible Numbers of Poles.

The cascade motor is essentially a low-speed machine; and it is when designed for speeds which are abnormal for single-field motors that it shows to best advantage. The numbers of poles for which the machine can be constructed are determined by the following conditions :—

(*a*) The numbers of poles in the two fields must be so chosen that their windings are mutually non-inductive.

(*b*) The two fields when superimposed must not produce an unbalanced radial pull on the rotor.

The first condition is satisfied when the numbers of poles are such that at the points where the axes of the two field systems coincide at any given instant, half of the poles of one system are reversed relatively to those of

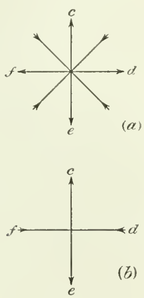


Fig. 1.

the other system. Fig. 1 (*a*) represents an 8-pole field, and Fig. 1 (*b*) a 4-pole field. The axes of the poles coincide at four points, *c*, *d*, *e*, *f*. The poles *c*, *e* are of the same polarity in each field, but the poles *f*, *d* are reversed; consequently the electromotive force generated in the 8-pole winding by the poles *c* and *e* of the 4-pole field is equal and opposite to that generated by the poles *f* and *d*. The 4-pole field acts in a similar manner upon the 8-pole winding. This method of illustrating the conditions is due to Mr. M. B. Field, and was suggested by him in the discussion of the previous Institution paper to which reference has already been made. The number of points at which the polar axes coincide is given by the "greatest common factor" of the two numbers of poles. In the example illustrated the numbers are 8 and 4, and the "greatest common factor" is 4. To obtain the necessary reversal of polarity it follows that at the points of coincidence all the poles of one field system must be similar, whilst consecutive poles of the other must be reversed. In other words the sector bounded by any two adjacent axes of coincidence must contain an even number of the poles of one field system and an odd number of those of the other field. Therefore, condition (*a*) is satisfied when the two numbers of poles are such that when divided by their "greatest common factor" the quotient is in one case an even and in the other case an odd number.

To satisfy condition (*b*) the two superimposed fields must give a symmetrical resultant field. From what has been said above it follows that at one-half of the points of coincidence the gap density will be large owing to the similar polarity of the two fluxes, whilst at the other half of the points the gap density will be low, as the poles of the two systems are of opposite polarity. To satisfy condition (*b*) the "greatest common factor" must be a number greater than two. The most usual numbers of poles are in the ratio of 2 : 1; for example, 8 and 4, 12 and 6, 16 and 8, and so on.

Stator Windings.

The experimental motor with two sets of windings proved satisfactory in that it showed that a single motor could be wound to operate with concatenated windings. Beyond this the test results were not encouraging; for owing to the presence of two sets of windings the losses were high; and as deep slots were required to accommodate these windings both the power factor and overload capacity were low.

Leaving the motor for a moment the author would like to refer to the idea which seems to be prevalent, that the coupling of two motors in cascade must always result in a very bad power factor. This idea is apparently due to the fact that the magnetizing current of two similar machines so coupled is twice that of one machine alone. Naturally a larger magnetizing current is required as the speed of the set is only one-half of that of one motor alone. If a motor wound for, say, 12 poles is compared with two 6-pole motors of the same diameter connected in cascade it is found that the power factor of the cascade set will only be slightly lower, the reduction being due to the increased inductance of the end connections owing to their greater length and to the slightly increased magnetizing current called for by the greater length of the iron path. Against this reduction in power factor due to increased leakage we have to set an improvement resulting from the fact that the rotor copper losses tend to improve the power factor. In an ordinary machine the resistance losses in the rotor do not influence the primary power factor, so that if the stator and rotor copper losses are equal, only half the total I^2R losses assist the power factor. In cascade-connected machines both stator and rotor carry magnetizing currents, so that if the losses are distributed in the same way, three-quarters of the total copper losses help to improve the power factor. Further reference to this matter is made in a later section of the paper.

Returning to the development of the motor, it was evident that to make the machine commercially successful a way had to be found to obviate the necessity for two separate sets of windings. What was required was a single winding suitable for two entirely independent currents, one at line frequency and the other at the frequency of slip. This was a stator problem; the treatment of the rotor windings, requiring a different solution, was left till a later date. The required winding had not only to be suitable for the circulation of these two independent sets of currents,

but had to be so connected that the induced or low-frequency currents could only circulate when paths outside the windings were provided for them. This was necessary in order that the starting torque and speed could be controlled by causing the induced currents to flow through

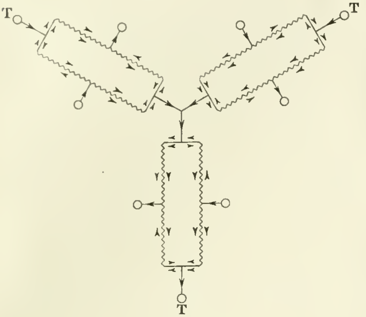


FIG. 2.

variable external starting or regulating resistances. Two sets of terminals were therefore required, one set for connecting to the mains and the other set to the resistances. The main currents must not be allowed to flow through the external secondary paths, and consequently it was essential that any one pair of secondary terminals should be connected to two points in the windings between which there existed no "main" potential difference. To meet these conditions a parallel-connected winding was necessary. Fig. 2 shows diagrammatically a form of winding which at once suggests itself. The main terminals are lettered "T," and the three pairs of tappings are those to which three separate sets of resistances would be connected for starting and speed-regulating purposes. When running at full speed each pair of tappings would be short-circuited. Arrow-heads shown inside the diagram indicate the direction of flow of the main currents at a given instant; those outside the diagram similarly show the direction of flow of the induced currents.

Having obtained this key diagram the next thing to be done was to find a winding which could be connected up in accordance with it. We shall now proceed to work out the winding again starting from this point. Fig. 3 shows the windings of one phase of an 8-pole stator. One slot per pole per phase is shown in order to simplify the diagram. Each radial pair of small circles represents the two coil sections occupying one slot, and the crosses and dots within the circles indicate the directions of flow of the main currents. Only the back connections of the coils are shown, as we have not yet found out how these coils are to be joined together. The main currents produce 8 poles, and we require to connect the coils so that induced currents generated by a 4-pole rotor field can circulate in them. This 4-pole field is shown in the figure, and we see that four of the slots containing coils are opposite the centres of the poles and four are situated between the poles. The electromotive forces induced by the 4-pole field in the parts of the windings in the slots in the centres of the poles are consequently in quadrature with those induced in the slots midway between the poles. Therefore the key diagram should be modified so as to provide for two-phase currents in each of the three sections of the star winding.

We can now make a new diagram which will permit of this (Fig. 4); and it is a simple matter to connect up the winding shown in Fig. 3 so as to comply with this key. With the 4-pole field in the position shown, the induced voltages and currents will be in the directions indicated by the dots and crosses shown outside the coil circles. Alternate coils are marked A and B, and all the induced currents in the A coils are in phase with one another and in quadrature with the currents in the B coils. In Fig. 4 the secondary tappings of one phase are marked A, B, to correspond with Fig. 3.

Working from terminal T_I and taking the left-hand path, we connect the top end of coil A_1 to the terminal and its bottom end to the secondary tapping A_x. To the same tapping we connect the top end of coil A_2 and its bottom end to the central bridge C. Also to this bridge is connected the bottom of B_1 with its top to the tapping B_x; and to the same tapping the bottom of B_4, and its top end to the neutral point N. Working up the right-hand path, A_4 top is coupled to T_{II}, and its bottom end together with A_3 top to the tapping A_y. To the bridge is connected A_3 bottom and B_2 bottom. B_2 top and B_3 bottom are connected to B_y, and B_3 top to the neutral point. Fig. 5 is the completed winding of one section of the stator, and the connections of the remaining two sections are carried out in exactly the same way. The arrow-heads in Fig. 5 refer to the induced currents only.

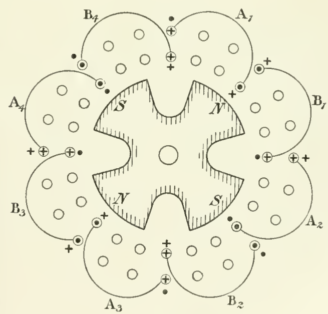


FIG. 3.

The application of this winding to machines having a larger number of poles introduces no difficulties. A winding for a machine with 24 and 12 poles would be connected in the same way, except that instead of there being only one coil in each section of the winding there would be three.

In Fig. 6, which is a winding for a motor having 8 main and 4 auxiliary poles, the currents induced by the 4-pole rotor field are indicated.

Values have been given in Fig. 6 to the induced currents. These have been obtained by assuming that the 4-pole field would induce a maximum electromotive force of 1 volt in any bar. The flux and electromotive force are assumed to follow a sine law. The inner circle of figures shows the electromotive force induced in the conductors in each slot at the instant under consideration. The electromotive force or current in each coil is obtained by adding together the voltages induced in the two limbs of the coil. Outside the diagram a ring of figures shows the net values of the currents in each slot, from which it will be seen that of the total ampere-bars 70·7 per cent are effective. Of course this could have been deduced from the fact that each slot carries two currents in quadrature.

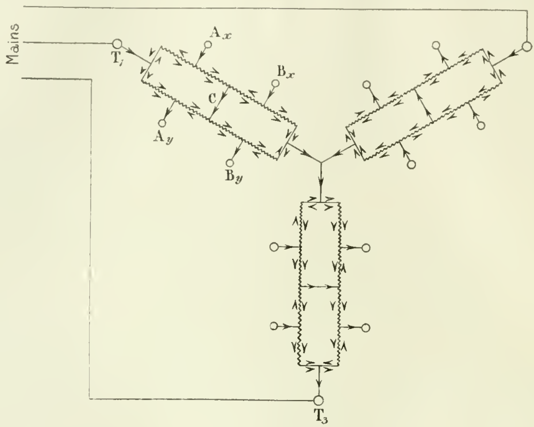


FIG. 4.

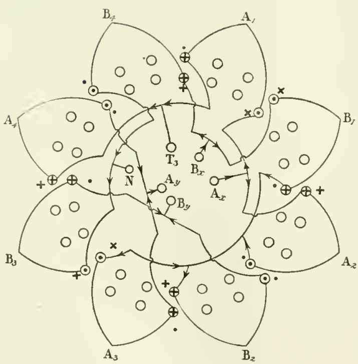


FIG. 5.

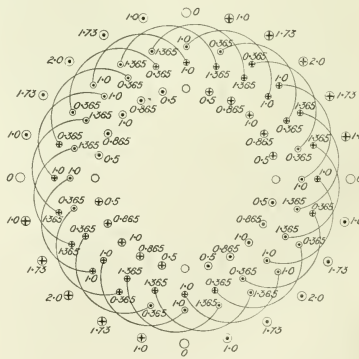


FIG. 6.

It may be well to mention that it is quite possible to

construct windings to fit the simpler key diagram of Fig. 2. A winding of the type that has just been considered could be used; but it would mean that in alternate slots the induced currents in the two coil sections would be equal and opposite and only one-half of the winding would be usefully employed by these currents. By using the winding shown in Fig. 6, the effective value of the ampere-bars is 70·7 per cent of the total ampere-bars ; so that a very considerable reduction in the secondary losses can be obtained by increasing the number of secondary leads. In practice this increased number of leads has not proved objectionable.

In the windings illustrated, the slot pitch has been made normal for the larger number of poles. If this be increased, then with three-phase secondary currents the effectiveness of the winding will be increased. If the windings were given a 6-pole slot pitch (equal to the average pitch of the two numbers of poles) the slot pitch factor would be increased to 0·865 for three-phase secondary currents, but of course the effective value of the main ampere-bars would then be reduced in the ratio of 1 to 0·865. Windings with three-phase secondary tappings and this average pitch have been used, but owing to the presence of additional leakage fluxes they are distinctly inferior to windings employing six-phase tappings. Such windings have three groups of conductors per pole as x-pole windings, but only three groups per pair of poles as $2x$-pole windings.

The winding shown in Fig. 6 may now be compared with the two separate windings of the original machine. This matter was dealt with fully in the earlier paper and it will only be necessary now to consider it briefly. In an average machine the number of the induced ampere-turns of the stator will equal about 46 per cent of the "main" ampere-turns. With two separate windings the total number will therefore be 146 if the main current produce 100. With a single winding the secondary ampere-turns will be 65, as the pitch factor is only 0·707. The heating effects of the two currents are proportional to the sum of their squares, so that a current equal to the geometrical sum of the two currents will have the same heating effect as the two separate currents. In this case this current will produce 119·5 ampere-turns instead of the 146 ampere-turns required with the double winding.

The whole of the copper being merged into one winding gives a greatly reduced effective value to the resistance, so that for a given weight of stator copper the I^2R loss is reduced to rather less than one-half.

Rotor Windings.

Having obtained the required stator winding, attention was next paid to the rotor. As both windings carry currents of the same frequency and no external connections are required, the treatment is quite different from that applied in the case of the stator. As with the stator winding, it will probably be clearer if we start from first principles and re-develop the windings. As there are only two axes of coincidence in a motor having 4 and 2 poles, such a machine is not practicable, as the shaft would be subjected to unbalanced radial forces. It will, however, save a lot of needless repetition if we work out the rotor windings for this number of poles. Such a winding when obtained forms a unit that can be used in the building up of windings for any other numbers of poles. For instance, a motor with 8 and 4 poles would have a winding consisting of two such units, a 20- and 10-pole motor would have five units and so on.

The strength of the auxiliary field of the motor is proportional to the electromotive force across the windings producing it, and inversely proportional to the number of turns per pole in the auxiliary winding. The strength of the main field is proportional to the same electromotive force if we neglect the pressure-drop due to resistance, and is of course inversely proportional to the number of turns per pole in the stator winding. We are assuming that the number of turns in the stator and the rotor (main field winding) are the same. The strength of the main field is determined by the number of turns in the stator winding, and by varying the relative numbers of turns in the two rotor windings the strength of the auxiliary field may be changed.

If the main rotor winding has twice as many turns as the auxiliary rotor winding then each will have the same number of turns per pole ; and as the area of an auxiliary pole is twice that of a main pole, the flux per pole of the second field will be twice that of the main field and the gap density of the two fields will be the same. The magnetizing current required for the auxiliary field will be equal to that required by the main field, and therefore the total magnetizing current of the machine will be twice that taken by the main field alone.

If both rotor windings are given the same number of turns, the rotor auxiliary flux will be halved and the gap density and the number of ampere-turns will also be halved. The number of turns being doubled, only one-quarter of the magnetizing current will be required to produce the auxiliary field, and the total magnetizing current of the machine will be 25 per cent greater than that required by the main field alone.

In practice the best results have been obtained with rotors having main and auxiliary windings in the ratio of 1·73 to 1·0. This ratio gives an auxiliary field with a flux per pole 73 per cent greater than the main flux. The gap density of the auxiliary field is 86·5 per cent of that of the main field, and the auxiliary magnetizing current is consequently equal to 75 per cent of the main magnetizing current, giving a total current 75 per cent greater than the main field current. With a given stator winding the magnetizing current of the auxiliary field varies inversely as the square of the number of turns in the auxiliary winding, and the reactance directly as the square of the number of turns. For windings in the ratio of 1·73 to 1·0 an average figure for the reactance of the auxiliary windings is 40 per cent of that of the main windings. It can be shown that for minimum leakage the winding ratio should be 1·414 to 1·0, which would give a total magnetizing current 50 per cent in excess of the main field current. Such a winding can be developed, but it requires deeper rotor slots to accommodate it and has to be wound for two phases. This winding together with a large number of others have been tried, but have all had a greater leakage than the 1·73 to 1 winding.

It has been assumed that the main stator and rotor windings have the same number of turns. It hardly needs to be pointed out that changing the number of

stator turns will not affect the relative values of the two fluxes. This relationship is dependent on the number of volts per turn; and any change in the stator equally affects the rotor.

Fig. 7 shows a developed diagram of a 4-pole winding. The slot pitch has been shortened to two-thirds the normal, so that bars carrying currents differing in phase by 60 degrees occupy the same slot. If the current per bar is 1 ampere, the effective number of ampere-bars per slot will be 1·73. The reason for choosing the shortened pitch is to reduce the ampere-bars per slot from 2·0 to 1·73. In the same slots is shown a two-pole winding of full pitch with 1 bar per slot. The two windings are interconnected magnetomotive force. We therefore omit these bars. There are now left 6 slots each containing only one bar, as shown in the figure below, the original 4-pole and 2-pole windings. In each of the slots containing 3 bars, two of the bars carry currents of the same phase, and the current in the third bar differs in phase from the others by 60 degrees.

If a conductor carry two currents of the same amplitude differing in phase by 60 degrees, the crest value of the resultant current equals 1·73 times the crest value of either of the component currents, and the phase of the resultant current lies midway between the phases of these component currents. This phase relationship is found in an interconnected star and mesh winding.

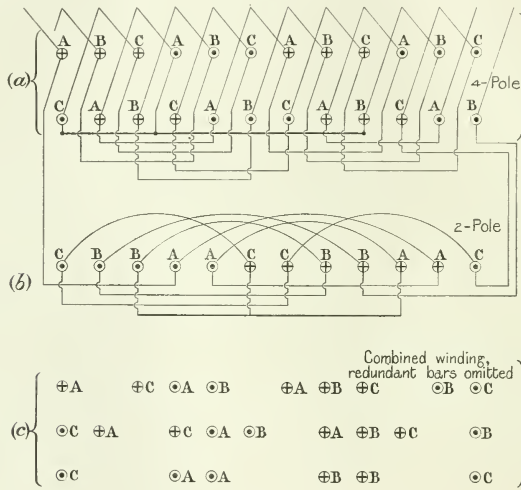


FIG. 7.

so that the same current circulates in each; consequently with 1 ampere per bar there are 1·73 ampere-bars in the 4-pole winding and 1·0 ampere-bar in the 2-pole winding in each slot.

In this diagram as well as in all the others in the paper instantaneous values of the currents are taken at the instant when the current in B is 1·0, and those in A and C 0·5 each.

From an examination of the winding it will be seen that in slots 2 and 3 there are two bars carrying currents of the B phase which are equal and opposite. In slots 6 and 7 the bars carry equal and opposite currents of the C phase, and the same conditions are found with currents of A phase in slots 10 and 11.

It is clear that two conductors carrying equal and opposite currents in the same slot can produce no useful

By connecting up the combination winding, Fig 7, to form a star and mesh construction we can use two bars per slot instead of three, and thus simplify the winding. It is only necessary to merge two bars carrying currents

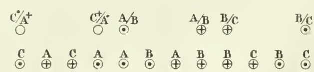


FIG. 8.

differing in phase by 60 degrees and call all such bars star bars. For example, in slot No. 1 the A bar and one of the C bars would be replaced by a single star bar. The slot conductors are now represented diagrammatically by Fig. 8,

and all that is required to complete the winding is to provide suitable end connections to give a star-mesh construction. This has been done in Fig. 9.

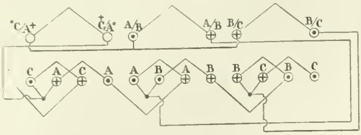


FIG. 9.

We can now compare the combination winding with the original construction in which two entirely separate windings were necessary. By combining certain of the bars we have not changed the magnetomotive forces produced by the component currents, although we have reduced the actual heating value of the currents from 2·0 to 1·73. The component currents still attain the same crest values which they had before we substituted single bars for two separate bars. As far as the magnetizing values of the currents are concerned, the skeleton winding in Fig. 7 is identical with the finished winding of Fig. 9, so that we may compare it directly with the original 4-pole and 2-pole windings of Fig. 7. If the 4-pole winding (Fig. 7) is divided in two by a vertical line between slots 6 and 7 it will be seen that the skeleton winding (Fig. 7) consists of nothing more than a re-arrangement of the original 4-pole winding. The C bar in slot 7 has been taken out and placed in slot 1. The B bar in slot 2 has been removed to slot 8, and so on; so that the combination winding which takes the place of the original 4-pole and 2-pole windings is only a non-uniformly arranged 4-pole winding. In its symmetrical form the two conductors in each slot might be replaced by a single conductor carrying an effective current equal to 1·73 times the current in each bar, so that the total section of copper would be $12 \times 1{\cdot}73 = 20{\cdot}76$ sq. mm., if for the sake of illustration we allow 1 sq. mm. per ampere and call the current in each single bar 1 ampere.

In the combination winding owing to its non-uniform nature there are only 6 bars carrying resultant currents of 1·73 amperes. The remaining 12 bars each carry 1 ampere. Allowing the same current density as before, the cross-section of the copper will be 22·38 sq. mm., or the combination winding will require 7·8 per cent more copper than the original 4-pole winding.

Electrically the winding shown in Fig. 9 was very satisfactory, since the end connections being in two planes at right angles to one another had low inductance. Mechanically the construction was not so sound, for centrifugal forces acted directly on the joints of the end connections and it was not easy to support the windings sufficiently without seriously reducing the ventilation. Further, the use of two different winding pitches was objectionable.

To overcome these weaknesses the arrangement of the end connections was changed and a barrel type of winding of the usual type was used. This is shown diagrammatically in Fig. 10. The slot pitch of all the coils is the same and the end connections can be supported on rings in the usual manner and held in position by binding wire. In appearance it resembles an ordinary rotor except that one-quarter of the bars have been omitted.

It is now proposed to investigate the voltages in the several sections of the winding in order to prove that the back electromotive forces induced by the 2-pole field are equal and opposite to those induced in the winding by the 4-pole field. The 2-pole flux per pole is equal to 1·73 times the 4-pole flux per pole. Under load conditions the 2-pole flux would be slightly less, so as to leave sufficient voltage to drive the current through the resistance of the windings. In Fig. 10 the bars have been numbered from 1 to 24, and in Fig. 11 the star-mesh key diagram is reproduced, the parts representing the different bars being numbered to correspond with Fig. 10. To find the voltages induced in individual bars we may make use of the original 4-pole and 2-pole diagram Fig. 7 and treat it as a voltage diagram. The voltages producing the 4-pole currents are in phase with them, but the back electromotive forces induced by the 2-pole field will be opposite in direction to the currents. We can therefore take the directions of the voltages direct from the 4-pole diagram, but the directions must be reversed when reading the 2-pole diagram. In doing this we are taking the maximum electromotive force per bar induced by the 4-pole field as 1·73, so that as the flux per pole of the 2-pole field is equal to 1·73 times the 4-pole flux, we must take the maximum electromotive force per bar induced by the 2-pole field as 3·0.

In Fig. 11 the double-barbed arrow-heads represent the 4-pole electromotive forces and the single arrow-heads the electromotive forces induced by the 2-pole field. A letter at the side of the arrow indicates the electromotive force and phase.

To make quite clear the method adopted, let us consider

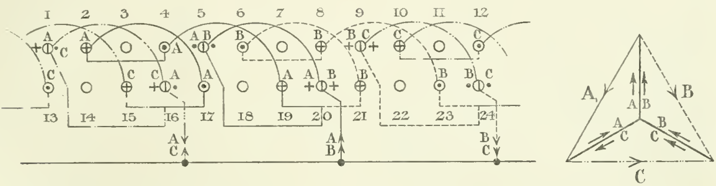


FIG. 10.

the ray of the star consisting of bars 20 and 5. Starting from the neutral point we first find the electromotive force in bar 20 due to the 4-pole field. This bar is situated in slot 8; and from the 4-pole diagram (Fig. 7) we find that the voltage across this bar is A B and from Fig. 10 we find that its direction is from the neutral. This we indicate on the star-mesh diagram by two double-barbed arrow-heads, marking them A and B. Referring now to the 2-pole diagram we find that the bar in slot 8 has a voltage 3 B induced in it; and remembering that this voltage will be opposite in direction to the current, we find that its direction is towards the neutral point. The next bar is in slot 5, and from the 4-pole diagram we see that the electromotive force is A B and its direction is from the neutral. From the 2-pole diagram we find the voltage is 3 A and its direction is towards the neutral. The voltages across each bar are determined in this way and indicated on the diagram. The arrows show the instantaneous directions of the currents, but we have to consider the amplitude of the electromotive force in balancing the voltages due to one field against those produced by the other.

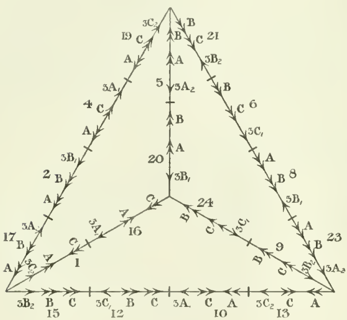


FIG. 11.

The 2-pole diagram (Fig. 7) which we are using to find the back electromotive forces is made up of pairs of bars of the same phase in adjacent slots. The phase will of course only be the same when the bars are connected in series. In taking the electromotive forces from this diagram a distinction is made by denoting the phases as A_1 and A_2; B_1 and B_2; C_1 and C_2. And as in each circuit there is an equal number of bars of each, the phase error is automatically corrected.

An inspection of the diagram shows that the voltages taken round the mesh are in balance. The 4-pole electromotive forces cancel out phase by phase, and the B phase electromotive forces of the 2-pole field are in opposition to those of the A and C phases. No currents can therefore circulate except by way of the star windings.

There are then only three circuits, and these are shown in Fig 12. Taking the left-hand circuit we find the 4-pole electromotive forces consist of 8 A and 4 B opposed to 4 C. Now the B and C electromotive forces differ in phase by 120 degrees, so that their resultant is an electromotive force in phase with A. The total electromotive force is therefore 12 A. Now taking the back electromotive force induced by the 2-pole field we find that the B and C electromotive forces cancel out and leave an electromotive force of 12 A opposed to the 4-pole electromotive force of the same value.

In the right-hand circuit the 4-pole electromotive force consists of 8 B, 4 C, and 4 A in the same direction. As before, the resultant of 4 C and 4 A is 4 B, so that the total 4-pole electromotive force is 12 B. The A and C electromotive forces produced by the 2-pole field cancel and leave a back electromotive force of 12 B. In the third circuit we find a 4-pole electromotive force of 12 C balanced by a 2-pole electromotive force of the same value. In other words the back electromotive forces in each circuit are equal and opposite to the electromotive forces induced by the main field.

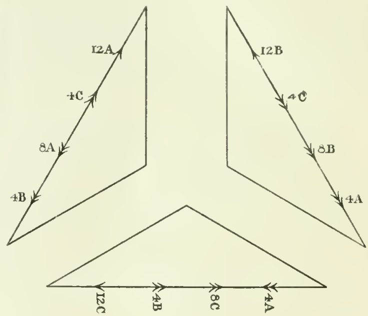


FIG. 12.

This completes the description of the cascade machine in its simplest form. In another section of this paper motors with two or more efficient speeds are described, but in these the extra speeds are not obtained by cascade coupling. The windings already described are used in all the machines, and only certain additions are made to the rotor to enable it to operate at non-cascade speeds.

THE ONE-SPEED MOTOR.

The completed motor closely resembles a machine of ordinary construction. The stator windings are identical in appearance, and only differ in the cross-connections of the coils. Standard construction is also used for the rotor. The efficiency and power factor curves of a 330 b.h.p. 50-cycle 200 r.p.m. motor having 20 main and 10 auxiliary poles are shown in Fig. 13. The gap diameter of the motor is 56 in. The stator slots are of the completely open type, and those of the rotor are semi-closed.

The slots are chosen to suit the main poles; therefore

if a 30-pole motor is to be designed having 20 main and 10 auxiliary poles and 3 slots per pole per phase, 180 slots would be required. With the same number of slots per pole, a motor of the one-field type would have 270 slots. As a two-field motor requires only two-thirds of the number of slots, it is possible to build motors of this type for a very large number of poles with reasonably

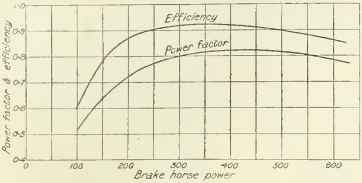


FIG. 13.

good power factors. As an example a motor which has been running in Scotland for some years may be cited. This machine has 28 main and 14 auxiliary poles and therefore operates at 42-pole speed, which is 140 r.p.m., as it is running on a 50-cycle circuit. The output of the machine is 100 b.h.p., and the gap diameter is 50 in. The power factor at full load is about 0·81.

The cascade machine has a very small slip because the resistance of the rotor does not directly affect it. In a one-field motor the no-load and stator copper watts are deducted from the watts input to the machine, and the slip is obtained by dividing the rotor copper loss by the net input to the rotor. In a two-field motor the slip is equal to the tapping copper loss divided by the net input to the machine. The net input is equal to the watts input of the motor less the no-load losses and the stator and rotor copper losses. As the whole of the stator copper forms the tapping circuits, the losses in these circuits are very low.

The efficiency of a cascade machine can be very easily calculated if the tapping current, stator resistance, and slip are measured. Knowing the tapping current, the losses in these circuits are known. The net input to the machine is found by dividing the tapping circuit loss by the slip; and the net input less the tapping loss is the output of the motor. The efficiency is of course found by dividing this figure by the gross input. By slip is meant the mechanical slip of the machine and not the slip of either field.

The core of a cascade machine has to carry both the main and auxiliary fluxes, but as the secondary flux is only rotating at the speed of slip the loss due to it is small and the flux density behind the teeth can be raised to a high figure. The density in the teeth must, however, be kept within reasonable limits otherwise the power factor may be considerably reduced. The actual iron loss in a motor of standard design is practically unaffected by the presence of the auxiliary field; with increasing density the second flux increases the losses considerably, but the normal working density is far below this part of the curve.

STARTING AND SPEED REGULATION.

The presence of the auxiliary field has a marked effect upon the behaviour of the motor when starting and "creeping." It gives the machine a more even turning moment; the motors will run quite steadily with resistances connected to the stator tappings at less than 1 per cent of their full speed, and at starting they develop a very steady pull. For these reasons the machines have been extensively used in the driving of all classes of hauling machinery, and they give satisfactory inching in the driving of printing presses and similar machines.

Owing to the very low-voltage windings used in the rotors and the absence of slip-rings, single-speed motors are found to be very successful in the driving of all classes of mining, cement, and quarry machinery, and they are now being introduced into rolling mills.

It is hardly necessary to say that machines of this type develop full-load starting torque with approximately full-load current, and that they can be designed to suit all conditions of starting. The standard design of motor starts against any load up to 2 to 2¼ times the full-load torque, and of course regulation of the starting torque is obtained by varying the resistances connected across the stator tappings. At full speed these tappings are short-circuited in the same way that the rings are short-circuited in motors of the slip-ring type.

Unless the machines are required to run at reduced speeds for a considerable time it is unnecessary to provide resistances for all the stator tappings. Tests made some time ago showed that with resistances connected to two pairs of tappings in one leg of the winding the motor would start against a torque equal to a little more then full-load. With three resistances, one in each leg of the star, the three pairs of tappings being so chosen that the stator coils carrying induced currents are symmetrically arranged round the stator, the motor starts against a torque approximately equal to its maximum running torque. With resistances connected to four pairs of tappings, the maximum starting torque is approximately the same as with three resistances. In the usual way either three or four resistances are used at starting and for moderate speed regulation, and the remaining tappings are

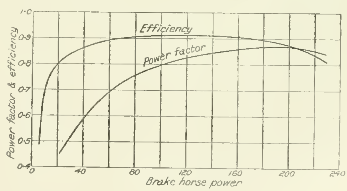


FIG. 14.

short-circuited when the machine has attained full speed. The short-circuiting of these extra tappings may be effected by contacts arranged on the starting switch, or by a short-circuiting switch mounted on the side of the stator.

The curves in Fig. 14 show the efficiencies and power factors of a motor recently built to an Admiralty specifica-

tion. The motor has an output of 150 b h.p. at 250 r.p.m. and is wound for a 380-volt 50-cycle circuit. It has 16 main and 8 auxiliary poles.

For motors required to run up to speed against, say, full-load torque or a somewhat higher torque, the resistances may be permanently connected across the tappings and when the main switch is closed the machine starts, developing its maximum torque. After it has speeded up, a short-circuiting switch, mounted on the side of the stator, is closed. Such an arrangement is equivalent to a squirrel-cage motor with a very high-resistance rotor. The short-circuiting switch allows the resistances to be reduced to a low value at full speed.

Two-speed Motors.

As the currents supplied to the main terminals of the stator winding (Figs. 4, 5, and 6) can only produce the main field, and as there can be no difference of potential between any pair of tappings unless the windings are acted upon by a field having a number of poles differing from those of the main field, it follows that if an ordinary slip-ring rotor wound for the same number of poles as the stator be substituted for the cascade rotor the machine will run as an ordinary one-field motor. The machine will run 50 per cent faster than with its own rotor, and will possess the usual characteristics of a motor of standard design, except that as the iron density will be rather lower the core losses will be less. The copper losses will be slightly increased as the motor has been made a little longer than an ordinary machine in order that there may be the necessary iron to accommodate the extra flux when running at cascade speed.

In the first two-speed motors two windings were used on the rotors, one wound for the same number of poles as the main flux and connected in star, and the other wound for half the number of poles and connected in mesh. Both windings had the same number of conductors, but as one was connected in star and the other in mesh, the current in one was 73 per cent greater than that in the other, and the ampere-bars of the two were in the correct ratio. From the points of inter-connection of the two windings leads were taken to 3 slip-rings. When the motor was required to run at cascade speed the slip-rings were open-circuited and the machine was started by resistances connected to the tappings. When required to run at non-cascade speed, the tappings were open-circuited and the motor was started by means of resistances connected to the slip-rings in the usual manner. When running at top speed the short-circuited slip-rings prevented any appreciable current from flowing into the second rotor winding. This type of winding required very deep motor slots in order to keep the losses down, and this made it very difficult to get enough iron into the teeth to prevent over-saturation.

Referring to Fig. 10 we have already noted that the cascade rotor winding is non-uniformly distributed. If the winding can be made uniform when desired, the second field can be suppressed and non-cascade speed obtained. To do this it is necessary that all slots should carry the same number of bars. The question then arises as to how these additional bars are to be connected to the others so that all shall carry the same current. It was a long time before it was realized that the desired result could be obtained very easily. All that is necessary is to take the cascade winding, Fig. 10, insert the three coils which were omitted, and connect one end of each to a slip-ring and the other ends to the middle points of the delta parts of the winding. The winding thus produced is shown in Figs. 15 and 16. The three slip-rings are open circuited and the currents shown correspond with those in Fig. 11 for cascade working.

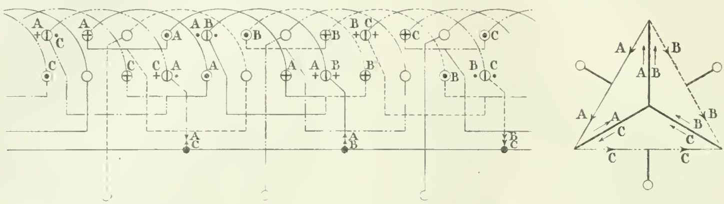


Fig. 15.

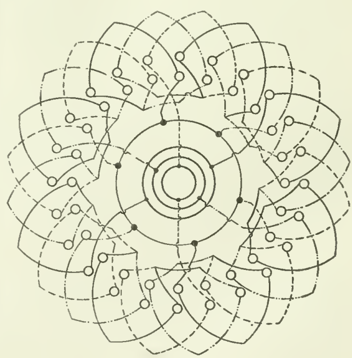


Fig. 16.

Let us now see what happens when the three slip-rings are short-circuited, as in Fig. 17. As before we are here considering the instant when the B current is 1·0 and the A and C currents each 0·5. We are also taking the electromotive force and current induced in each bar as simply A, or B, or C, because it is no longer necessary to consider this as made up of two component voltages. We see that at each point where three bars meet, the B current divides into A and C currents, so that each point is in reality a neutral point, and there are 8 such points in the winding.

The key diagram, Fig. 17, is drawn in the form of a star and mesh so as to be exactly comparable with the cascade key, but it does not show correctly the phase relationship of the currents. Fig. 18 is the corrected diagram, and it can be divided into 4 parts as shown, namely, 4 interconnected star windings. The currents must necessarily all have the same amplitude and they will all be controlled by an ordinary three-branched resistance connected to the slip-rings.

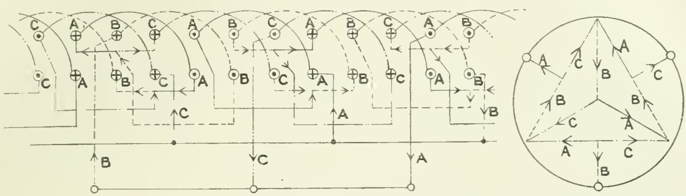


FIG. 17.

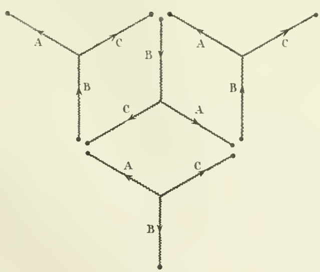


FIG. 18.

In extending the winding for use with a larger number of poles either parallel or series connections may be used. If the former plan is adopted, the key diagram would be a 12-sided figure for a machine wound for 8 main and 4 auxiliary poles, and to each slip-ring would be connected two leads from diametrically opposite points. For larger numbers of poles the diagram is extended in the same way, the number of sides of the figure being equal to the total number of poles (main + auxiliary) of the motor, and the number of parallel connections to each slip-ring being equal to one-sixth of this number of poles.

If series connections are used, similar coils in each block of 4 poles of the winding are connected together; and for any number of poles there will be one connection to each slip-ring and the diagram will be a hexagon.

The weight of copper in this type of rotor winding is less than one-half of that in the original double windings; and as quite shallow slots will accommodate it the reactance is naturally very much less. The construction of the winding follows standard lines for barrel-type rotors, and any rotor with this type of winding can be made to give the extra cascade speed by changing its cross connections.

CHARACTERISTICS OF THE TWO-SPEED MOTOR.

A motor of this type is designed in exactly the same way as a machine of the ordinary type wound for the main number of poles. Of course the teeth and core are given appropriate areas to carry both fluxes when the motor is running with its second flux; and the depth of the slots is kept down so that the leakage will not be excessive when operating at cascade speed. Keeping these points in mind the windings are worked out for the main number of poles, as experience has shown that the maximum torque developed in cascade will be approximately the same as when the machine is working with only one field.

A word should be said with regard to the calculation of the cascade power factor. In ordinary designs the effect of the stator resistance on the power factor is generally but small. This is not so in a cascade-connected motor, especially if it is wound for low speeds, because unlike a one-field motor the rotor copper loss as well as the main current loss in the stator windings have the effect of increasing the power factor. Therefore as the tapping loss is only small, nearly all the copper loss helps in improving the power factor. The reason for this is the presence of magnetizing currents in the rotor windings. The rotor resistance has a much larger effect on the power factor than the stator resistance, because when the rotor is running at cascade speed the frequency of the currents in its windings is only approximately one-third of the line frequency. The author has found it convenient to calculate the currents in the various circuits with the rotor

standing; and when this method is used it is necessary to give the rotor resistance a fictitious value equal to 3 times the true resistance, in order that its relationship to the reactance may be the same as when running at cascade speed. Actually the figure should be slightly less than 3, owing to the slip. The exact figure is equal to $r_m/(r_m - r)$, where r_m is the synchronous speed of the main field and r the speed at which the rotor is running.

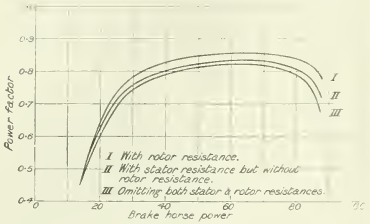


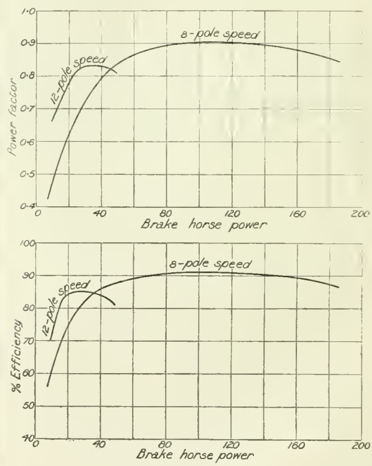
FIG. 19.

To show the effect of the resistance losses three curves have been drawn, Fig. 19, one showing the calculated power factor curve ignoring the resistances, the second including the stator resistance, and the third taking into account the effect of both stator (main circuit) and rotor resistances. The motor is of standard design giving 50 b.h.p. at 500 r.p.m. on a 50-cycle circuit, and consequently having 8 main and 4 auxiliary poles. Some crane motors which had quite average efficiencies and power factors and large overload capacities were found on test to take less current on quarter load than when running light. The iron was highly saturated, and owing to the resistance drop the magnetizing current fell off rapidly as soon as the machines were put on load.

These characteristics are of course common to machines having any number of speeds, one of which is obtained by concatenation, and would perhaps have been more in place in the section dealing with the one-speed cascade machine. It has already been mentioned that the pull-out torque of the two-speed motor is approximately the same at both the speeds, and in an earlier section of this paper it was shown that the no-load current at cascade speed exceeds that at non-cascade speed by 75 per cent. When a motor is required to drive a fan or any machine which requires less torque at its second speed than at full speed, a star-mesh switch is mounted on the motor so that the machine may be run with its stator windings connected in mesh at full speed and in star at cascade speed. This arrangement reduces the no-load current at cascade speed to one-third of its usual value, or 58 per cent of the full-speed current. The overload capacity is similarly reduced, but is ample for a fan driven at two-thirds its normal speed. The arrangement brings the cascade power factor well up on the curve and also permits of the use of a smaller motor, because the machine at cascade speed is operated with a main flux reduced to only 58 per cent of its value at full speed. The machine can therefore be designed for standard densities at full speed.

The curves in Fig. 20 are those of a two-speed motor driving a colliery fan. The machine gives 120 b.h.p. at 580 r.p.m. and 30 b.h.p. at 397 r.m.p. on a 40-cycle circuit, and is wound for 2,750 volts. It operates at 8-pole and 12-pole speeds, but as deeper slots than the standard were required to take the high-tension windings the power factor at the second speed is a good deal below the figure for low-voltage machines. Any speeds between the limits of 397 r.p.m. and 580 r.p.m. are obtained by resistances connected to the slip-rings, and speeds below 397 r.p.m. by resistances connected to the stator tappings.

In the majority of cases speeds below cascade are not required and the control of the machine can then be considerably simplified. The curves in Fig. 21 show the power factor and efficiency of a high-tension motor which is used to drive a compressor at a colliery. This motor gives 550 b.h.p. at 243 r.p.m. and 370 b.h.p. at 164 r.p.m. on a 50-cycle circuit. An ordinary rotor starter is used, and on the side of the stator is mounted a 6-pole switch for short-circuiting the stator tappings. When the maximum quantity of air is required from the compressor the machine is started and taken up to full speed by the rotor starter in exactly the same way as an ordinary motor. When a smaller quantity of air will suffice the motor is

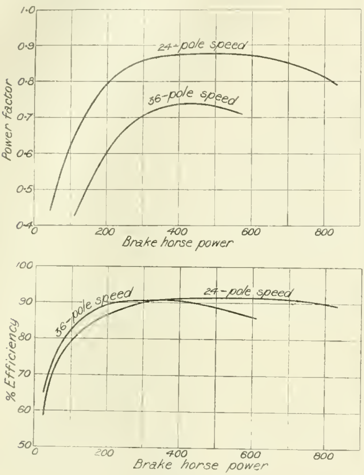


FIGS. 20A AND 20B.

started as before by means of the rotor resistance and is brought up to approximately cascade speed. The tapping short-circuiting switch is then closed and the rotor starter open-circuited. It is not necessary to bring the speed exactly to its cascade value before closing the switch, but

the nearer it approaches it the smaller will be the jump in current.

Quite a large number of machines are running which are started from rest by simply closing the stator tapping switch when cascade speed is required. This is quite satisfactory if the momentary rush of current is not an objection and the starting torque required does not exceed the full-load torque. Motors of 50 h.p. have been started in this way, and owing to the cascade coupling the momentary current on first closing the switch is 30 per cent less than would be the non-cascade current under similar conditions.



FIGS. 21A AND 21B.

Reference has already been made to two-speed crane motors, and a few particulars relating to their sphere of usefulness and method of control may be of interest. For operating foundry cranes the single-speed machine is generally used on account of its inching qualities; but two-speed motors are used for the longitudinal motion of travelling cranes in long shops. When travelling with a load the machine runs at the second speed, and the high speed is only used when the crane is travelling light. The controller, which is generally of the tramway type, is provided with three extra contacts with an extra high-speed notch. When the motor is required to run at top speed the controller handle is brought over to the extra notch, in which position the stator tappings are opened and the slip-rings are short-circuited. This arrangement is very simple and has proved entirely satisfactory.

In the applications mentioned an attempt has been made to give a few typical examples of the uses to which these motors have been put, and this list, very incomplete as it is, will serve to illustrate the characteristics of these motors.

Their application to the driving of winding engines and rolling mills is a development of recent date. Two winders have been put into commission in South Africa during the last few months, and figures will shortly be available by means of which it will be possible to compare their characteristics with those of other winders of similar capacity of the Ilgner, Ward-Leonard, and the plain induction motor type.

Fig. 22A is a diagram of a complete wind when an ordinary induction motor is used; and the companion diagram, Fig. 22B, gives the same particulars for a two-speed motor drive. Comparing these diagrams we see that the R.M.S. output of the ordinary induction motor is 530 b.h.p., whilst that of the cascade motor is 490 b.h.p. There is a reduction of 2·8 units per wind in favour of the two-speed machine, omitting the energy returned to the line during retardation. The maximum input required by the ordinary motor during a wind is 1,225 b.h.p. and the corresponding input of the cascade machine is 1,035 b.h.p., showing a reduction in the peak of nearly 16 per cent. The depth of the inclined shaft is 5,000 ft., the incline being 65 degrees. The maximum winding speed is 2,500 ft. per minute, and the motor is wound for 500 and 333 r.p.m. on a 50-cycle circuit. The duty is 10,000 lb. of ore per wind.

For a given torque the output of a motor is proportional to its speed, and the input in a one-speed machine is the same at all speeds, the surplus input being absorbed in resistances. The cascade machine has two definite speeds at which there are no external rheostatic losses, and the input at the second speed is consequently only two-thirds of that at the top speed for the same torque. The actual input will be 1–2 per cent more than this, as the efficiency at the second speed will be reduced by this amount. Neglecting the internal losses of the motor, and considering only the acceleration torque, Fig. 23 is the starting diagram for a one-speed motor, and Fig. 24 a similar diagram for a two-speed motor. The shaded areas represent the losses in external resistances during the acceleration period, and the unshaded rectangle in the second diagram shows the saving in resistance losses effected by the use of a two-speed machine.

The second diagram shows the conditions which obtain when the torque is kept constant during the whole of the accelerating period. Up to cascade speed the input is reduced by 33 per cent, as has been explained above, and one-half of the input, measured as horse-power-seconds, during this period is lost in resistances. Above cascade speed the input has to be increased by 50 per cent, but as the motor has now attained two-thirds of its full speed the resistance losses during the second stage of the acceleration period are only one-half of one-third of the input measured in horse-power-seconds.

For two speeds in any ratio, let

$$K = (\text{second speed})/(\text{full speed}).$$

Then the input during the first stage of the wind $= K^2 W t$ watt-seconds, where W is the input and t is total time of acceleration.

The lo… during this period of the wind will be $0{\cdot}5\ K^2 W t$.

The input during the second acceleration stage $= (1 - K) W t$ watt-seconds; and the corresponding resistance loss is $0{\cdot}5 (1 - K)^2 W t$.

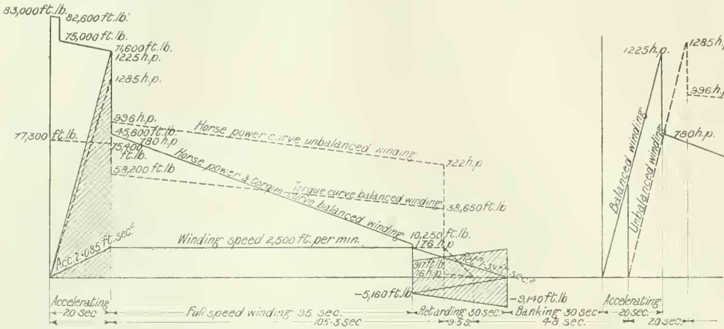


FIG. 22A.—Power Diagram of Slip-ring Winder Motor.

R.M.S. output (balanced), 530 h.p. R.M.S. output (unbalanced), 830 h.p.
Units per wind = 17. Units per wind = 27.

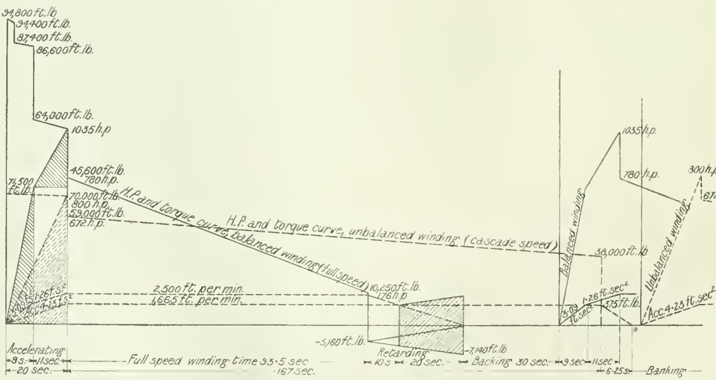


FIG. 22B.—Power Diagram of Two-speed Cascade Winder Motor.

R.M.S. output (balanced), 490 h.p. R.M.S output (unbalanced), 534 h.p.
Units per wind = 14·2. Units per wind = 25·4.

The total loss during acceleration is

$$0{\cdot}5\ W t [K^2 + (1 - K)^2].$$

As $0{\cdot}5\ W t$ is the acceleration loss of a one-speed motor, the expression in brackets represents the two-speed losses as a fraction of such loss. If we deduct this fraction from unity and multiply by 100, we obtain an expression which gives the percentage reduction in these losses. This simplifies to $200\ K(1 - K)$.

For the smallest possible loss $K = 0{\cdot}5$, or the second speed is half the top speed, and the reduction in the rheostatic losses is 50 per cent. In the case of the winders under discussion $K = 0{\cdot}66$, and the percentage reduction in the losses is $200 \times 0{\cdot}66 (1 - 0{\cdot}66) = 44$ per cent.

These figures show that with a two-speed motor having speeds in the ratio of 3 : 2, the efficiency during acceleration is 64 per cent, and with a one-speed machine 50 per cent.

So far we have only considered a motor developing the same torque during both stages of the acceleration period, with an input during the second stage 50 per cent greater than during the first stage. This is not the correct way to control a winder, as the first essential is to reduce the peak load as much as possible. In order to attain this result the input should be the same during the whole period of acceleration; this gives up to two-thirds full speed, an acceleration 50 per cent greater than that during the

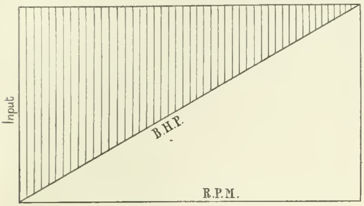


FIG. 23.

remaining part of the period. The diagram for these conditions is shown in Fig. 25.

Let us now compare this diagram with that for constant torque (Fig. 24). However we may change the relation of the torques during the two acceleration stages, the kilowatt-seconds input for each stage will be the same if the acceleration efficiencies are not affected. A glance at the diagrams shows that during the first stage the efficiency must always be 50 per cent. In the second stage the input usefully employed is

$$\tfrac{2}{3}\,W_2 t_2 \cdot \tfrac{1}{2} \cdot \tfrac{1}{3}\,W_2 t_2 = \tfrac{5}{6}\,W_2 t_2,$$

which is also constant and gives an efficiency of 83·3 per

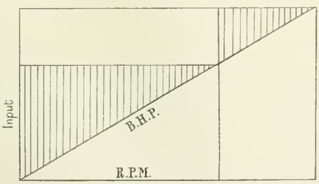


FIG. 24.

cent. Therefore we can study the question from the point of view alone of reducing the peak load, knowing that however we may vary the control we cannot lose the 44 per cent reduction in the external resistance losses.

The shaded areas in Figs. 22A and 22B represent the losses. These are dissipated in resistances during acceleration and in brake friction during retardation. Whilst slowing down to cascade speed the motor is driven as a generator by the load and returns energy to the line. Below this speed the brakes are applied.

With regard to the controlling gear, this is arranged so that resistance is automatically cut out of the stator tappings until the machine has attained two-thirds speed. The next step connects resistances to the rotor, and opens the stator circuits, and the rotor resistances are reduced until they are finally short-circuited with the motors running at its full-speed. The cascade system offers the advantage of gradual change from cascade to full-speed coupling with the motor connected during the whole time to the line. The stator is never disconnected from the mains until the brakes have been applied and the motor has been brought to rest.

For the reasons already stated there is no fierceness in the control at creeping speed and when starting; consequently decking is under complete control.

A modification of the stator windings, described later, enables us to reverse the main and auxiliary fields so that instead of there being $2x$ main poles and x auxiliary poles, the former has x poles and the latter $2x$ poles.

It is immaterial to the rotor windings whether the main or auxiliary fields have the greater number of poles when operating in cascade; the currents distribute themselves

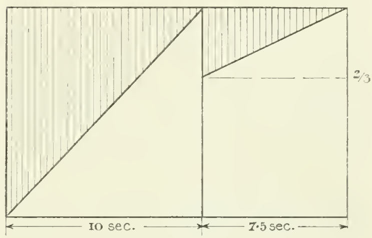


FIG. 25.

in the windings in exactly the same way under either condition.

With the slip-rings short-circuited the current distribution is changed, as is explained in the section dealing with three-speed motors; but beyond requiring slightly more copper no alteration in the windings is necessary. With this arrangement of windings the motor has two efficient speeds in the ratio of 3 : 1, and electric braking can consequently be obtained down to one-third of full speed.

Fig. 26 is the acceleration diagram of a motor with this speed ratio. From the general formula which has already been worked out we find that the rheostatic losses with speeds in the ratio of 3 : 1 are the same as for a speed ratio of 3 : 2. That this is so can be seen from the diagram, for with constant input the torque will be three times as great at cascade speed as when running on the slip-ring, so that the machine will run up to one-third speed in one-seventh of the time that it takes to reach full speed. If Wt be the total input in kilowatt-seconds, $Wt/14$ will be the loss in resistance during the first stage of acceleration. At the commencement of the second stage the motor will have attained one-third speed, and the resistance loss

whilst accelerating to full speed will be $\frac{1}{2}(\frac{2}{3}\text{ W})(\frac{6}{7}\,t) = \frac{12}{42}\text{ W}\,t$. The total losses are $15/42\text{ W}\,t$, and the amount usefully employed is $27/42\text{ W}\,t$. The efficiency is $27/42\text{ W}\,t \div \text{W}\,t = 64{\cdot}3$ per cent, which is the same as for a speed ratio of 3 : 2. It is therefore possible to obtain the same reduction in acceleration losses and peak load with this type of motor as with the one previously considered; but with constant input the torque attains a very high value during the first acceleration stage. Fortunately a motor with this speed ratio is capable of developing a considerably larger maximum torque at cascade speed than at top speed, so that the conditions for minimum peak are not impossible of attainment.

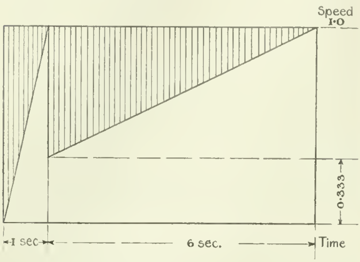


FIG. 26.

WINDINGS FOR SPEED RATIOS OF 3 : 1.

Instead of describing the finished winding the author proposes to adopt the same procedure as before and develop it from first principles. As the currents in all windings are to be confined to definite paths, we have not the help of a squirrel-cage construction to damp out harmonics, and we must therefore decide to work with three groups of slots per pole for both main and auxiliary fields.

Let us work out a stator winding suitable for a motor having 4 main and 8 auxiliary poles. The main field calls for 12 groups of slots, and the auxiliary field for 24 groups. Consequently each group carrying line currents of one phase must be so arranged that it can be divided to carry induced currents of two phases. Assuming that we are going to use a star winding, each leg will have to be arranged to permit of the circulation of two induced currents of different phases. The key diagram will therefore be the same as that used before (Fig. 4).

The next question to be settled is the slot pitch. Obviously this cannot be made equal to the normal pitch of a 4-pole machine, because if this were done all the coils would exactly embrace two poles of the auxiliary field, which could induce no electromotive forces in them. On the other hand we cannot use a normal 8-pole pitch, for with such a short pitch a satisfactory 4-pole winding would be impossible. An average of the two must be chosen, and this will give us a pitch coefficient of 0·865 for both numbers of poles.

We can now draw a diagram (Fig. 27) showing one main phase of this winding and fill in the phases of the line currents A, B, and C. Outside the circles the induced currents X, Y, and Z, are shown. The same convention has been adopted as before, namely, the instantaneous values of the currents in phases B and Y is 1·0, and those in A and X and C and Z 0·5 each. The cross-connections are now drawn, the method followed being exactly the same as before, except that each ray of the star is now made up of two groups of coils situated in adjacent slots instead of a whole pole-pitch apart. The secondary currents are three-phase, although there are still six secondary circuits.

Each slot carries two sets of wires, the currents in which differ in phase by 60 degrees, so that the number of effective ampere-wires per slot is equal to the number of ampere-wires per set of conductors multiplied by 1·73.

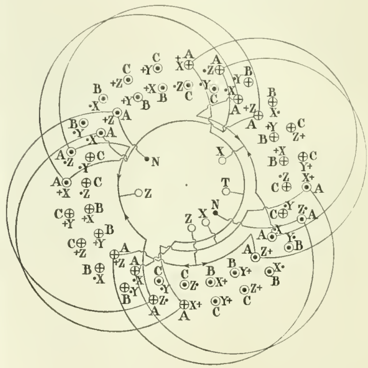


FIG. 27.

This applies to both the main and induced currents, and is due to the contraction of the 4-pole slot pitch by 60 electrical degrees and the extension of the 8-pole pitch by the same angle. The slot-pitch coefficient is necessarily the same for both fields, and is of course equal to the cosine of half the angle of contraction or extension, that is to say it is 0·865.

The arrangements for the control of a two-speed motor with this winding do not differ from those previously described.

The machine is used where a large difference between the two efficient speeds is required, or where regeneration down to low speeds is desired. Reference has already been made to this in connection with electric winders. For electric lift work it is also useful, since besides allowing for electric braking and regeneration it makes it much easier for the lift attendant to bring the cage to rest when exactly level with the landings. The "creeping" properties of the motor are also available as the machine is operating in cascade.

The rotor winding for a (4 + 8)-pole motor is given an 8-pole pitch and is identical with the winding for an (8 + 4)-pole machine. The distribution of the currents when the slip-rings are short-circuited and the motor is running at 4-pole speed is quite different from the state of affairs that exists when the winding is working with an 8-pole field, because the slot pitch is contracted to one-half the normal. This is explained in the next section of the paper.

Three-speed Motors.

The two-speed motor can be operated at a third speed if the stator windings be so arranged that they can produce two different numbers of main poles. For example, a two-speed motor wound for 8 main and 4 auxiliary poles, and running at 750 and 500 r.p.m. on a 50-cycle circuit, can be made to run at a third speed of 1,500 r.p.m. by changing the stator winding in such a way that the line currents will produce a 4-pole field.

The (4 + 8)-pole stator winding (Fig. 27) can be used for this purpose if the two groups of coils of each phase are divided and the neutral point is opened as shown in

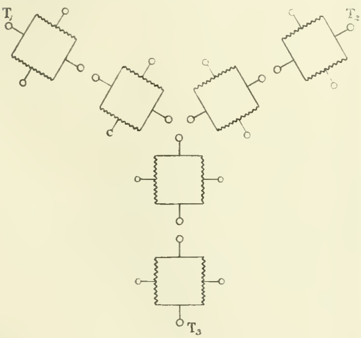


Fig. 28.

Fig. 28. To connect this winding for 8 main poles, we place in series two groups of coils in adjacent sections and then by means of a suitable switch connect the whole winding to form a star, Fig. 29.

Fig. 30 shows the winding re-connected to give 4 poles. The diagram is self-explanatory. This winding requires a large number of terminals, but as the switch for changing the number of poles is mounted on the side of the stator frame this is of no great moment. Unless speed control is required below cascade speed (and this is seldom necessary) the switch for short-circuiting the tappings is also fixed on the stator frame, and then the only external connections are the three line wires and three leads to the slip-rings.

As stated before, the type of rotor winding used for a three-speed motor is identical with that shown in Figs. 15, 16, and 17, and as a motor wound to run at non-cascade speeds corresponding to 8 and 4 poles and a cascade speed corresponding to (8 + 4) poles, would have a winding with a full 8-pole slot pitch, the rotor winding of Fig. 16 would be suitable for it.

The (4 + 2)-pole two-speed winding, Figs. 15 and 17, is reproduced in Fig. 31, and the phase of the electromotive force induced in each conductor by a 2-pole field is indicated by the letters A, B, and C in the key diagram, Fig. 33. Again, the instantaneous value of the B-phase voltage is 1·0, and the A and C phase voltages 0·5 each.

An examination of the relative phases of the electromotive forces in each coil will show that those between the mesh and the slip-rings and between the mesh and the neutral point differ in phase by 60 electrical degrees, and the resultant maximum electromotive force is therefore equal to 1·73. In each coil in the mesh part of the winding the two electromotive forces differ in phase by 120 electrical degrees, and their resultant maximum electromotive force is therefore equal to 1·0. Where the electromotive forces in one of these coils belong to phases A and C, the resultant electromotive force is B; where B and C, the resultant is A; and where C and A, the resultant is B. Fig. 34 is the key diagram with these resultant electromotive forces substituted for the two component electromotive forces.

We see from Fig. 34 that the winding has now taken another form, which may be described as a double star-mesh. At each point where three coils meet, the electromotive forces in any two of them give a resultant equal, as regards both amplitude and phase, to the electromotive force in the third conductor. There will therefore be no distortion of the electromotive forces, and these will therefore produce currents in phase with them.

We can now indicate these electromotive forces as currents in the rotor winding diagram and study the distribution of them (Fig. 31). In each slot one of the components of the current in a star bar differs in phase by 120 electrical degrees from the current in the mesh bar, and consequently the resultant of these two currents has the same amplitude as, and is in phase with, the second component of the star current. That is to say, currents in both bars in each slot are equivalent to a single current of twice the amplitude, and of the same phase, as one of the components of the star current. As we have assumed that the amplitude of a single current is 1·0, the heating value of the ampere-bars per slot is $1·73 + 1·0 = 2·73$, and the actual magnetizing value of the ampere-bars is 2·0.

To illustrate this further, let us consider the currents in slot 1. The star bar carries a current made up of two components of phases B and C, and the mesh bar carries a current of phase A, its direction being opposite to that of the component currents in the star bar. As the B component and the A current differ in phase by 120 electrical degrees, the effects produced by them are the same as those which would be produced by a single current of the same amplitude as either of them, and consequently equal to, and of the same phase as, the component current C. As far as the magnetizing effects of the currents are concerned we may then represent them by substituting equi-

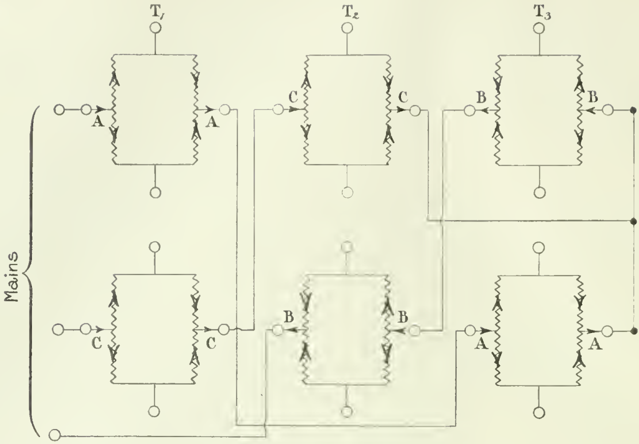


FIG. 29.

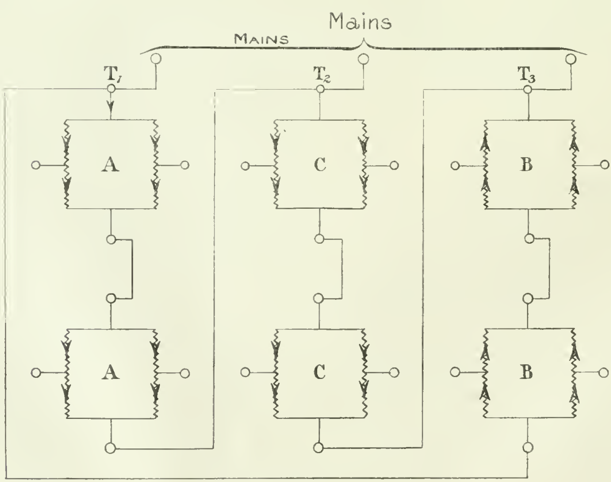


FIG. 30.

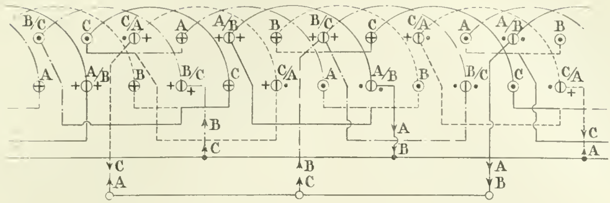


Fig. 31.

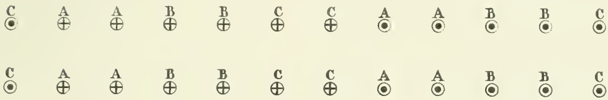


Fig. 32.

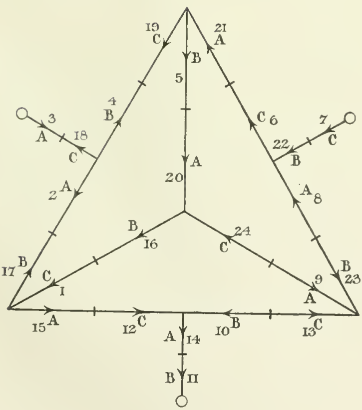


Fig. 33.

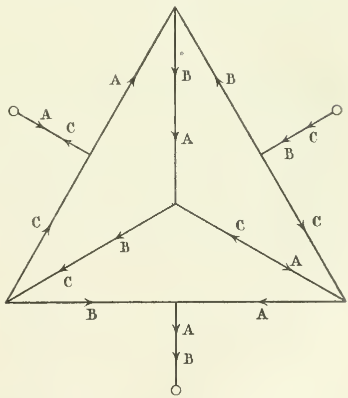
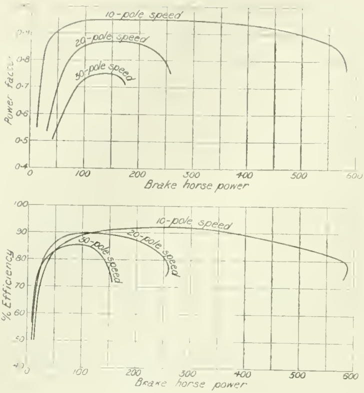


Fig. 34.

valent currents for the actual currents. This has been done in Fig. 32.



FIGS. 35A AND 35B.

Particulars of two three-speed machines may be of interest; the first was built to the specification of Mr. G. H. T. Hooghwinkel, and drives an air compressor at a colliery in South Wales. It gives 400, 200, and 133 b.h.p. at speeds of 300, 150, and 100 r.p.m. on a 25-cycle 2,200-volt circuit. It is wound for 10, 20, and (20 + 10) poles.

The second machine gives an output of 300, 150, and 100 h.p. at speeds of 300, 150, and 100 r.p.m., on a 25-cycle, 440-volt circuit. The efficiency and power factor curves of this motor are shown in Figs. 35A and 35B. This machine also drives an air compressor used for refrigerating purposes.

This concludes the description of the machine as it stands at the present time. It would be futile to say that its development is complete, for cascade operation is full of possibilities, and we have only recently seen an entirely new development in the speed regulation of induction motors by various methods employing a commutator machine coupled in cascade with the main driving motor. Experiments are now being made with a view to developing a self-starting synchronous motor from the machine described in this paper, by substituting continuous current for the induced stator currents, and starting the machine as an induction motor by resistances connected to the slip-rings. Again, a combination giving a large number of speeds is possible by coupling a change-pole type of squirrel-cage motor in cascade with a two- or three-speed machine, and it is hoped that in the near future something may be done in this way.

In conclusion, the author takes the opportunity of expressing his thanks to those who have so greatly assisted him in the preparation of this paper. To Messrs. T. M. Dutton and H. C. Carter for the various diagrams, and to Messrs. Kilburne and Munzell for the curves reproduced in the paper.

MANCHESTER LOCAL SECTION, 10TH FEBRUARY, 1914.

enberg. DR. E. ROSENBERG: This paper describes the results of at least eight years' hard work on the part of the author in developing one of the most fascinating problems of electrical machine design, namely, the superposition of currents in the same winding. The motor itself is only a little more complicated than the ordinary induction motor, but there seems to be some difficulty in using liquid controllers for these motors, and also in winding the stators for such pressures as 3,000 to 6,000 volts, for which ordinary induction motors are easily wound.

Cramp. MR. W. CRAMP: It is well known that alternating-current problems may frequently be simplified by substituting for

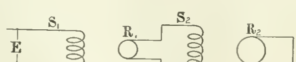


FIG. A.

the actual conditions an equivalent circuit made up of resistances and reactances, with variables to represent the variable factors in the original circuit. Such a plan may be pursued in the case of the cascade motor, and in my opinion it results not only in presenting the problem in a simpler manner, but also in showing how the vector equation may be written down correctly. Thus in a cascade motor or concatenated pair of induction motors, let S_1 (Fig. A) be the stator of the first motor, having across its terminals the potential difference E, and let R_1 be the rotor of the first motor. Let S_2 and R_2 represent corresponding parts of the second motor. Then the equivalent electrical circuit is represented by Fig. B, wherein the suffixes 1 and 2 refer to the respective motors. The small letters denote complex quantities, and have the following usual meanings: $y =$ stator admittance; $z =$ stator impedance (including reactance due to leakage flux only); $r =$ rotor resistance; $x =$ rotor leakage reactance. If the frequency of the supply be denoted by N, the revolutions of either motor by n, and the number of pole pairs for which either motor is wound by p_1 and p_2 respectively, then the frequency in the first stator is N, and in the first rotor and second stator it is $N - p_1 n$, while the frequency in the second rotor is $N - (p_1 + p_2) n$. Thus in order to represent the circuit conditions exactly, r_1 and r_2 must be assumed to vary with the speed. They then become— Mr. Cramp.

$$\frac{N}{N - p_1 n} r_1 \text{ and } \frac{N - p_1 n}{N - (p_1 + p_2) n} r_2 \text{ respectively,}$$

while x_1 and x_2 remain constant. The magnetizing current of the first motor flows through the admittance y_1 at constant frequency N, while that for the second motor flows

Mr. Cramp

through y_2 with varying frequency $(N - p_1 n)$. From this simple diagram, without writing down any equation, we may at once draw the following conclusions and contrast them with the statements made by Mr. Hunt:—

1. The first speed at which the torque becomes zero is when $(p_1 + p_2) n = N$, and the torque of the combination there changes sign. But if the combination be then driven faster, the torque may reverse again before $N = n$, and this will assist the combination to run up to its higher speed when used as a two-speed motor. Resistance in the second rotor reduces this tendency; but with a normal short-circuited rotor it should be very noticeable, although the author does not mention it.

2. It is clear that the behaviour of the motor up to a speed $N/(p_1 + p_2)$ may be approximately expressed by a circle diagram. This diagram becomes simple if the product $e_1 y_1 z_1$ be neglected, so that $e_1 y_1$ is constant; and more simple still if the current $e_2 y_2$ be supposed to be added to

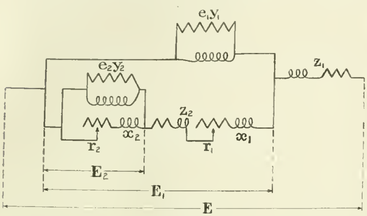


Fig. B.

$e_1 y_1$, and z_1 be added to z_2. On account of the varying frequency in the reactance z_2, such a diagram can be used with tolerable accuracy near the point of synchronous

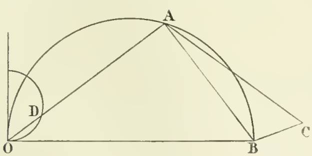


Fig. C.

Current Scale.—
B C = Sum of magnetizing currents $(e_1 y_1)$ and $(e_2 y_2)$.
B A = The current in both rotors and the second stator
Voltage Scale.—
O D = Pressure-drop in the resistance components of Z_1 and Z_2.
D A = Product of rotor current into $\left(\frac{n}{n - p_1 n} r_1 + \frac{n - p_1 n}{n - (p_1 + p_2) n} r_2\right)$.
B A = Product of rotor current into the reactance X_1, X_2, and the reactance components of Z_1 and Z_2.

speed of the second motor, if the reactance component of z_2 be calculated for this speed. Fig. C is this diagram on the assumption of a ratio of transformation of unity for the windings; and the various corrections for greater accuracy are easily deduced from Fig. B.* The influence of the rotor and stator resistance is easily seen and may be compared with the author's remarks on pages 408 and 415. A fact which he neglects is the variation of the magnetizing current of the second motor; this is evidently much smaller and more variable than the magnetizing current of the first motor. This fact contradicts the statements made by the author on page 411 concerning the relationship between the main and auxiliary flux and the main and auxiliary windings, and helps to explain the practical advantage that ensues from different values of the main and auxiliary ampere-turns.

3. In order that the cascade motor may compare with the ordinary induction motor it is clear that the resistances, reactances, and admittances of the cascade pair must not exceed the corresponding values for the ordinary machine. It is in this direction that the author has been so successful, and the combined windings which he has developed have in this their chief importance.

4. The statement made by the author, to the effect that cascade connection of motors is the same as cascade connection of transformers, is seen to be untrue. For the frequency throughout both the transformers is identical, but in the second motor it is lower than in the first. Further, the fact that the first motor develops part of the mechanical power is another cause of difference in the analogy.

It is interesting to see what results one gets in practice from these motors. Some five years ago I put certain machines into operation and the following figures show the results obtained on test as compared with the ordinary slip-ring motors supplied by other firms:—

	Slip-ring Type	Slip-ring Type	Cascade Type
6-h.p. Motor			
Speed ... (r.p.m.)	480	1,420	500
Air-gap ... ... (in.)	0·026	0·0197	0·0235
Efficiency	80 %	82 %	83 %
Power factor	0·69	0·85	0·78
12-h.p. Motor			
Speed ... (r.p.m.)	570	570	500
Air-gap ... ... (in.)	0·026	0·0197	0·0235
Efficiency	82 %	85 %	83 %
Power factor	0·76	0·82	0·83

	Slip-ring Type	Cascade Type
15-h.p. Motor		
Speed ... (r.p.m.)	750	500
Efficiency	86 %	85 %
Power factor	0·80	0·83
30-h.p. Motor		
Speed ... (r.p.m.)	750	500
Efficiency	87 %	86 %
Power factor	0·87	0·85

In all the above cases the prices were practically equal when switchgear was included; so that the superiority

* For similar approximate diagrams and corrections, see W. Cramp and C. F. Smith, "Vectors and Vector Diagrams," especially Figs. 83, 84, 95, 109, 110, and 111.

Mr. Cramp. of the cascade motor for low speeds is very obvious. On page 411 the author states that there is no objection to the increased number of leads. As long as the starting switch can be fixed on the motor this is all right, but if it has to be mounted away from the motor then the cost of the cables is a distinct objection. On page 419 the author refers to the use of the cascade motor for crane work. He says that the machine can be used for cranes. But I think it does not get over the main trouble with induction motors for such work. With series motors and proper resistances very slow movement of the motor with light loads may be obtained, but what happens with the induction motor and the cascade motor is that when there is with a large resistance in the rotor, so as to get "inching," heavy loads, the motor runs away if the load decreases. I think I ought to say, however, that the operation will be better with the cascade motor than with the ordinary induction motor.

At the commencement of the paper the author says that the behaviour of the cascade motor is similar to that of two motors in series on continuous-current circuits. In view of the control question he should say, similar to that of two shunt motors. Is it not true that on his principle the La Cour converter could be made with its two windings on the rotor together, so that its two machines would be merged into one? The stator would then become like the stator of the ordinary series-wound alternating-current commutator motor. Perhaps the author will say in his reply whether he has considered this problem.

Mr. Aldous. Mr. F. C. ALDOUS: The author refers to the improvement in the power factor of the cascade motor due to the resistance of the rotor, and refers to a 50-h.p. motor. This improvement is obtained at the expense of efficiency, and would be smaller for machines of greater output. The same effect is observed due to the resistance of the stator in the case of a normal induction motor where the measured power factor on load is found to be appreciably higher than that calculated from the no-load and short-circuit currents by the Heyland diagram or by the Steinmetz method. This difference may amount to from 4 per cent to 6 per cent on motors up to 50 h.p., but is reduced to 1 or 2 per cent on large machines. The reference to the motor which took less current at quarter load than at full load is interesting. A highly saturated cascade motor will actually take under certain conditions practically constant current at all loads up to full load. The author is to be congratulated on having made it possible to manufacture the cascade motor commercially, because along with the many advantages which that motor possesses there are inherent disadvantages as compared with the slip-ring motor. The periphery of a motor may be divided into what may be described as the "winding space" and the "flux space," the units of which are respectively a slot and a tooth. Whereas in the ordinary slip-ring motor the whole of the flux in a tooth and the whole of the ampere-wires in a slot act upon one another, in the cascade motor two fluxes exist in the tooth and, in effect, two sets of ampere-wires in the windings, and each flux acts upon one set of currents only. In this feature the cascade motor is analogous to a two-speed induction motor with two separate windings. In the last-mentioned case one complete winding is always idle, but the whole of the tooth is utilized with the active winding; in other words, no "flux space" is ever wasted. As a result of the super- Mr. Aldous. imposed fluxes the value of $d^2 l$ for a cascade motor must be greater than that for a normal induction motor of the same output built under similar conditions. In addition to this, when limited by the saturation of the iron the cascade motor requires a considerably greater depth of stator core in order to carry the two fluxes, thereby increasing the cost of the machine and to a greater extent the overall dimensions. It will be found that for machines designed under similar conditions on the same frame and with the same air-gap, from 15 to 20 per cent less output is obtained with the cascade motor than with the normal slip-ring motor. The power factor of the two machines is about the same and the efficiency of the cascade motor is slightly less. The performance figures given by Mr. Cramp may be correct, but they are of little value for comparative purposes, since no figures are given for the relative overload capacities of the different machines.

The author states on page 415 that the cascade motor can be built either with a smaller diameter or with a higher power factor than the one-field motor. Many low-speed one-field motors with two and three slots per pole per phase in the stator and rotor respectively are built with power factors of 0·8. A cascade motor could be built with a smaller diameter only by using two slots per pole per phase for the primary number of poles; this would give a very low power factor. A further disadvantage is the small choice of speeds, the possible speeds with a 50 ∾ supply being 500, 333, and 250 r.p.m., whereas with the normal motor the speeds over the same range would be 500, 428, 375, 333, 300, 273, and 250 r.p.m. From the point of view of the manufacturer this small range of speeds might be an advantage if the machine to be driven could always be adapted to one of the available speeds. The author has referred to the even turning moment of the cascade motor at low speeds. A well-designed slip-ring motor gives a very even turning moment at low speeds, and it is doubtful if anything better is needed. Mr. Cramp evidently misunderstood this remark of the author, who referred to the even torque developed from point to point, and not to the speed variation with varying torque. In the case of a delicate operation such as lifting a pattern from a mould, a great deal depends on the crane driver. Even squirrel-cage motors with high-resistance rotors have been found to give excellent results with sufficiently skilful drivers. The application of the two-speed cascade motor for the driving of winding engines is of great interest, and if feasible should result in a considerable saving of power. The author's remark on page 419, that "This means a reduction of 2·8 units per wind," is rather misleading. The number of units per wind is in no way dependent upon the R.M.S. value of the output of the driving motor. In fact, in certain cases the number of units per wind might be lower for a greater R.M.S. value. The saving could never be quite as great as that shown, since the cascade connection could never take the motor quite up to cascade speed owing to the slip and to the fact that resistances are always in circuit. A disadvantage is that the tapping voltages are high, especially on a 3,000-volt motor, where the electromotive force between the tappings would on reversal be of the order of 2,000 volts and might cause flashing over in the controller. I believe the case referred to by the author is for 2,000 volts; the electromotive force between tappings

Aldous. on reversal would then be of the order of 1,400 volts. The control gear would also be complicated, and it is doubtful if many mining engineers would be prepared to sacrifice the simplicity of the slip-ring motor for a slight reduction in the energy consumption.

Shaw. Mr. W. BOLTON SHAW: When the author read his previous paper* doubt was expressed by some of those who took part in the discussion as to whether there was any real advantage in being able to run a three-phase motor at two speeds. I think it is now generally accepted that there are many advantages. The author mentioned a number of applications of the cascade motor. One application to which I should like to refer and which has not been mentioned in the paper is their use for driving large dock pumps. Some years ago I was interested in a scheme where three-phase electrically-driven pumps of over 1,000 h.p. were put forward in competition with engine-driven pumps. The heads against which the pumps had to lift varied from a few feet to over 40 ft., and with the cascade motor arranged for three and even two speeds the scheme put forward was very favourable. The advantage of getting rid of slip-rings in mining work, and particularly on high-speed motors, is obvious, and there is one direction in which it appears to me that the cascade motor would have considerable value if it could be applied, *i.e.* the driving of high-speed pumps. I understand that up to the present time the problem is one which has not been solved, and that the cascade motor is only designed to run at speeds up to 500 r.p.m.

Professor Marchant. Professor E. W. MARCHANT (*communicated*): The author gives in his paper many facts which should be of great value to designers of cascade motors, such as the most desirable ratio to use for the two rotor windings in order to obtain the greatest winding efficiency for the motors. Data such as these are the result of long and arduous experiment, and they cannot fail to be of value to electrical engineers generally; the paper indeed is one which I am sure will, in the future, be a standard for reference on these motors. During the last few months we have had the opportunity of testing a 10 h.p. motor which has been presented to the Electrical Engineering Department of Liverpool University by Messrs. Sandycroft, and I think the results which we have obtained may be of some value. With this motor the power factor when the motor was running at full speed and maximum load was 0·88. When running at cascade speed the current was 30 amperes and the power factor 0·76. The slip at full-load speed was 5 per cent, and on cascade it was 8·8 per cent with the rated current of 21·5 amperes. One of the best and most useful features of this motor is the ease with which a powerful starting torque can be obtained with the cascade connection. In order to obtain this result with ordinary induction motors, large and expensive starting resistances have to be employed; in this case, with the very simple form of liquid starter fitted, with drums containing less than a quart of soda solution, regulation to give full-load starting torque was easily made, and the motor was, if not easier, at least as easy to start and regulate as a continuous-current motor. A motor of this type, in which a powerful starting torque is obtained so easily, should prove of the greatest value for such purposes as lifts or cranes, or for railway operation.

* *Journal I.E.E.*, vol. 39, p. 648, 1907.

Professor Marchant. Speaking generally, the drawback to cascade motors is that there are two sets of windings, one for each of the cascade motors, even when the windings are combined, as they are in this motor, on one armature. The natural consequence of this is that the motor becomes relatively inefficient, since there are two sets of copper losses when the motors are running in cascade. One of the many improvements made by the author on the original cascade motor is in having so designed his windings that these losses are minimized by the balance of the currents in the two windings, whenever this is possible. The cascade principle, as the author points out, is capable of further development, but even the development up to the present time has enabled a motor to be produced which possesses qualities that the engineer of a few years ago would have regarded as almost impossible for an induction motor; perhaps the greatest of these is that the motor can run continuously at two or even three speeds without regulating resistances of any kind, and that its efficiency at the lower speed is almost as high as it is when the speed is the greatest possible.

Mr. Hunt. Mr. L. J. HUNT (*in reply*): Dr. Rosenberg referred to the possibility of using liquid controllers with cascade motors. Controllers of this type have proved entirely satisfactory and have been largely used for all voltages up to 2,200. It must be remembered that the pressure across a pair of tappings is only about 30 per cent of the line voltage, so that even with 2,200-volt motors the pressure across each liquid starter at the moment of starting is less than 700 volts. Motors for pressures up to 3,300 volts are in regular operation, and no insulation troubles have been experienced. Of course the controllers must be insulated for the full line voltage to earth, and by making liberal use of porcelain there is no difficulty in doing this. In the case of two-speed motors where no speed regulation is required below cascade speed, the starting switch is connected to the rotor and only a short-circuiting switch, mounted on the stator itself, is required.

Such an arrangement is not possible in the case of winding engines; and for high-voltage machines, in order to simplify the gear as much as possible, it will be well to return to a double winding for the stator—one winding for the line currents and the other for those induced by the second field. The saving that is effected by the use of a single winding is not nearly so great in the case of motors used for driving winding engines, because they are nearly always wound for high voltages. If two distinct windings are used, the one wound for high tension may be wound for one coil per pair of poles, so that there will be only one coil section to be insulated in each slot instead of two. This results in a considerable reduction in the space occupied by insulation. The secondary winding will be wound for, say, 500 volts, and will have only three terminals, so that a controller of standard construction may be used. The use of two stator windings will necessitate an increased length of core, and in a 3,000-volt machine of, say, 600 b.h.p., a drop in the efficiency of something less than one per cent. It will entail an increase in the cost of the motor of $7\frac{1}{2}$ to 10 per cent, but this will be more than counterbalanced by the saving in the controller.

It is always valuable to have a case presented from a different point of view, and by introducing the circle diagram, Mr. Cramp has made the theory of the machine

Mr. Hunt. clearer. He referred to the possibility of a cascade or two concatenated motors running at speeds other than cascade. The top speed of a two-speed motor is reached when $p_1 n = N$, and if the stator tapping switch is closed and the slip-rings are open-circuited, the motor will continue to run at full speed although connected in cascade. If the tapping switch be opened and the motor be allowed to slow down to a speed slightly higher than the mean of the full and cascade speeds, and then the tapping switch be closed again, the machine will accelerate to its top speed. If, on the other hand, the speed be allowed to fall slightly below the mean speed, the machine will develop negative torque and the speed will fall to its cascade value. When running at full speed and connected in cascade the second field is very small, for the frequency of the induced stator currents is approximately $p_2 N/p_1$ and a very small field will induce the necessary voltage to overcome the impedance of the stator winding. If a cascade motor be connected to the supply mains with its stator tappings closed, and if it be run up to speed by starting and running up the generator driving it, it will run through cascade speed to full speed. This will only happen if it is running absolutely light; but as the torque developed is extremely small, it will not run above cascade speed if belted to a loose pulley. When started with resistances connected to the tappings, it is absolutely impossible for it to pass cascade speed.

Mr. Cramp referred to the variation of the magnetizing current of the second field. In pointing out the effect of the rotor resistance on the power factor, I omitted to mention specifically the causes of this. In a motor of ordinary construction the effect of stator resistance is twofold. It improves the power factor by causing the magnetizing current to decrease with increasing load, and it also shields the rotor windings from a part of the stator self-induction, and thus reduces the demagnetizing component of the rotor current. In a cascade motor this effect is increased by the presence of magnetizing currents in the rotor winding, so that both the stator and the rotor resistances reduce the demagnetizing components of the currents in the tapping circuits, and decrease the magnetizing current of the second field.

Mr. Cramp has misunderstood the statement on page 411 with reference to the relative values of the magnetizing currents. The statement refers to the values of the currents at no load, and the knowledge of their respective values enables us to determine the coefficients of mutual inductance.

He also finds fault with the comparison of the cascade coupling with two transformers connected in series; here again the disagreement is more apparent than real. It is stated on pages 417 and 418 that it has been found convenient to calculate the characteristics of a cascade motor when the frequency is the same in all the windings, that is to say when the machine is at rest; and it is when so treated that the circuits of the motor are identical with those of two transformers connected in series.

I do not think there would be any difficulty in merging the two separate machines forming the La Cour converter into one machine in the way suggested by Mr. Cramp; in fact a patent covering such a machine has been in existence since 1906, but lack of time has prevented experiments from being carried out on these lines.

Mr. Aldous also referred to the effect of the resistance of the rotor windings on the power factor, and mentioned that any improvement that can be obtained is at the cost of the efficiency. This is only true within certain limits, and to illustrate my meaning let us consider a motor of ordinary construction. Here the stator resistance can improve the power factor, but the rotor resistance can have no effect upon it. Let us suppose that means are at hand to ensure effective cooling of the stator windings; then we may cut down the cross-section of the stator copper and correspondingly increase the area of the rotor copper so that the total copper losses remain the same as in the original machine. In this way we can greatly improve the power factor without reducing the efficiency. In the cascade motor the greater part of the copper loss directly affects the power factor, and it is for this reason that these losses have a greater effect upon the power factor of cascade motors than do those of ordinary machines. The improvement in power factor by stator resistance (the only resistance effect in ordinary motors) is shown in Fig. 19 (curve II).

With regard to the question of relative dimensions, Mr. Aldous is comparing ordinary motors having semi-closed stator slots with cascade motors having open stator slots, and since he had the opportunity of making such comparisons numerous modifications in the designs have been found possible. Recent experiments have shown that it is possible to increase the density in the iron at the back of the slots; and in the latest designs of these motors the iron has been so much reduced that in many cases its depth is determined by mechanical requirements only. It is true that in the stator there are two distinct currents, but as they both flow in the same windings the heating value is only equal to their geometrical sum. There is considerably less copper in a cascade motor than in a one-field machine, and after allowing for the absence of slip-rings, short-circuiting gear, and brush-lifting devices, the works cost of such machines is lower than that of slip-ring machines of the same rating. In comparing cascade motors with slip-ring machines made by one of the largest manufacturers, it has been found that, for a given rating, the diameters are approximately the same, and the lengths 10 per cent greater. Mr. Aldous mentions that one-field motors are built with two and three slots per pole per phase in the stator and rotor respectively, when wound for low speeds; but the same equally applies to cascade machines, so that the latter still only require two-thirds the number of slots of the ordinary machine.

I quite agree with Mr. Aldous that a well-designed slip-ring motor will develop a fairly even turning moment at low speeds, but it is a question of degree, and the fact remains that the cascade machine is so superior in this respect that it is constantly being specified to drive machines where creeping is required, because manufacturers of ordinary machines are unable to give the necessary guarantees.

Professor Marchant mentions 8·8 per cent as the slip of a small motor which he has been testing. There must have been some resistance in the circuit to account for this excessive slip. When tested at the works the figure obtained was $2\frac{1}{2}$ per cent.

Yorkshire Local Section, 11th February, 1914.

Pohl

Dr. R. Pohl: The author has undoubtedly succeeded in turning an almost purely theoretical idea into a practical machine, and the electrical industry owes him a debt of gratitude. This, however, need not prevent us from criticizing his paper. Very frequently when a new machine or appliance has been perfected for practical use it is applied not only within but beyond the borders of its legitimate field, where its use does not represent either an improvement or an economy. This, in my opinion, applies to the cascade motor when it is employed as a constant-speed machine. Its legitimate field lies within the wide range of variable-speed work, and I think it requires more than common enthusiasm to adopt it in place of an ordinary induction motor for constant speed. Let us analyse its advantages and disadvantages. Comparing it with a squirrel-cage motor it has only serious disadvantages, and where the starting torque required permits of the use of a squirrel-cage motor the cascade motor is obviously inapplicable. Coming to the slip-ring machine, the cascade motor for constant speed has the advantage of not possessing slip-rings. Superficial observation might lead one to think its rotor is equivalent to a squirrel-cage rotor. This, of course, is far from being the case. A squirrel-cage rotor, besides having no slip-rings, does not rely for its performance on any insulation; and in modern examples it has no soldered joints. It is therefore free from the four chief causes of trouble possible in a slip-ring rotor, namely, short-circuits, earths, bad joints, and slip-ring trouble. The cascade rotor only avoids the last, and so far from being free from possible trouble due to short-circuits or earths, it seems to me that there is a danger of such faults being more detrimental here than in the ordinary slip-ring machine. I should like to ask the author whether there is not under certain conditions the possibility of a cascade motor running up to a speed above the normal if short-circuits or earths occur in the rotor. For example, since a two-speed cascade motor for 500 and 750 r.p.m. is made to run at the higher speed by short-circuiting certain points in the rotor winding, cannot unintentional short-circuits cause a motor, designed for a speed of 500 r.p.m. only, to race until its speed reaches 750 r.p.m. The absence of slip-rings is undoubtedly a very valuable feature, but it must be considered that only the constant-speed cascade motor, and not the two-speed or three-speed motor, is without slip-rings, that this constant-speed motor is essentially a low-speed machine, and that the slip-rings which it is proposed to displace would naturally be fitted with brush-lifting and short-circuiting gear, and would run at a low speed. Whilst I admit that high-speed slip-rings for large and continuous duty are probably the most vulnerable part of a machine fitted with them, I suggest that the kind we are here considering, if properly designed and made, is a highly reliable and straightforward piece of mechanism requiring practically no attention. The absence of such slip-rings in the cascade motor has been obtained at what I consider to be far too great an expense, namely, not only a complication in the rotor windings themselves, but a more serious one in the stator windings. These must always consist of two parallel circuits, necessitating twice as many conductors in the stator as in any ordinary machine—a serious disadvantage in all machines, but particularly so in high-tension machines. Then there is the addition outside the symmetrical coils of a large number of joints and connections (which form the weakest part in windings and should always be kept down to a minimum), an extraordinary number of leads and terminals, a starting resistance consisting of 3 or 4 individual resistances connected by a large number of cables to the windings, and a type of winding very difficult to follow and almost impossible for any ordinary works or colliery electrician to repair. In addition to these disadvantages, the power factor of the machine is rather worse due to the long end connections, and the magnetic field consists of two superimposed fields creating a very high peak at one point equal to the arithmetical sum of the two maxima, thus necessitating low average densities in order not to reach saturation at this point. Dr. Pohl.

On coming to variable-speed work, we reach the legitimate field of the cascade motor. I was particularly pleased with the application shown for colliery winding-plants, and other cases where frequent starting and stopping are needed. I believe that here is a wide field which presents many opportunities for useful application of the author's motor. I do not consider it is applicable, however, to colliery fan-driving except in rare instances. The author has given an example of a fan drive on page 418, where a fan has to run at between 400 and 600 r.p.m. on a 40-$\sim$ circuit, requiring 30 h.p. at the bottom speed and 120 h.p. at the top speed. I suggest that a better solution of this engineering problem would have consisted in the use of a 120-h.p. slip-ring motor, designed with no other view than the best possible operation at its full power at 600 r.p.m., and of a 30-h.p. squirrel-cage motor direct coupled on to the shaft of the 120-h.p. motor, and designed for a speed of 400 r.p.m. I take it that the fan in question would generally be run at the top speed during the week and at the bottom speed at week-ends. The small squirrel-cage motor might be simply connected to the mains without any starting gear, and the installation would be simple, highly reliable, and economical in first cost and running cost. It should be pointed out, however, that in the vast majority of cases the speed variation required for a colliery fan is less than 33 per cent, and as the cascade motor unfortunately does not give a smaller speed-step than in the ratio of 3 to 2, it is generally impracticable to take advantage of it for colliery fan-driving.

I was particularly interested in the author's remarks on inching. The question whether a motor is suitable for inching work or not depends of course on the uniformity of the starting torque, irrespective of the relative position of the rotor slots to the stator slots. Some years ago I carried out a series of experiments to determine the variations in the starting torque of 3-phase motors as a function of the position of the rotor. As a result, I am able to state that if the number of slots in the rotor and stator is carefully chosen so as to get as nearly as possible uniform magnetic reluctance, it is possible to obtain almost exactly constant starting torque. To obtain this, it is also desirable to skew the rotor slots by one slot pitch. Motors made in

Dr. Pohl. this manner present no difficulties when used for inching work.

In conclusion, I would venture to express a somewhat bold opinion on the general principle of cascade control, and I am not thinking of the author's ingenious motor only, but also of the many other applications of this principle for obtaining varying speeds in 3-phase plants. I believe that it is a kind of "blind alley" development. It certainly has brought us nearer to the goal, *i.e.* a 3-phase motor variable within wide limits without speed steps and comparable with a continuous-current interpole motor, but it can only lead a certain distance towards this goal, and we shall ultimately have to retrace our steps and reach our destination by another route. It looks at the present time as if this different route would involve the use of commutators; but even this may not be the ultimate outcome of the work on which many keen investigators are engaged at present. I hope that Mr. Hunt, who has shown such admirable skill, ingenuity, and patience in the development of the cascade motor, will also apply these qualities to the development of a machine which lies in a more direct line of progress than, in my opinion, the cascade motor seems to do.

Mr. Wright. Mr. H. H. WRIGHT: In spite of what Dr. Pohl has said in criticism of the Hunt cascade motor I think it has a distinct, though limited, field of usefulness, which cannot be filled by either the slip-ring or squirrel-cage induction motor. For winding engines, haulage, and printing machinery, it is distinctly an advance on account of its smooth starting and large torque with a moderate current at very low speeds. It would be interesting to hear whether the author has applied this motor to the propulsion of ships, and if so with what result. I think it might there be applied with success, particularly if the frequency of the current supplied by the alternator could be varied so as to increase the range of speed. On page 414 the author mentions in connection with the one-speed motor that the stator slots are of the completely open type. This being so, are the slots bridged over with a narrow strip of iron after winding is completed, and are the stator coils former-wound?

Mr. Burnand. Mr. W. E. BURNAND: Where a heavy starting torque is unnecessary I believe that a plain squirrel-cage rotor with a pole-changing arrangement on the stator, similar to that described last year by Messrs. Nicholson and Haigh,* would be equally efficient and somewhat more simple than the cascade arrangement; but of course, owing to the combination of the starting torque with efficient speed variations obtained in Mr. Hunt's machine, I think there is a certain field for this which is filled more efficiently by the cascade arrangement than by any other machine at present available. One of the first things that impressed me in connection with the paper was the widely varying application of similar principles with which we keep coming into contact: for instance, the recent developments in extra-high-frequency alternators for use in wireless telegraphy involve substantially the same principles as the Hunt cascade motor, whilst Fig. 2 shows the same principle that is utilized in the phantom circuit of ordinary telegraphy, whereby two circuits are made to act as three without interference.

I wish to make two very minor criticisms of the paper, the first being that I do not think the analogy given in the opening paragraph under "General Principles" a good one. The two continuous-current machines mentioned by the author would only run at the speeds mentioned if they were shunt-wound with the fields in parallel and the armatures in series; also the speed ratios are dependent on the relative voltages of the two machines and have nothing to do with the poles; whereas the cascade principle in alternating-current machines is a matter of poles and not of voltage ratios. The continuous-current analogy also does not involve the double transformation of power for the second motor. The second point is on page 408, where it is stated that "in an ordinary induction motor the resistance losses in the rotor do not influence the primary power factor." This statement is often made when describing the circle diagram for the induction motor. Whilst this is undoubtedly correct for a given input to the motor, also, for a given torque, it is not correct for a given output which is really the purpose for which the motor is used. As is well known, to increase the resistance of the rotor increases the slip in practically the same proportion as the resistance without affecting either the ampere input or the power factor for the same torque; but to obtain the same power in watts or horse-power, obviously the torque must increase in the same proportion as the speed decreases. Considering the circle diagram, therefore, to get this increased torque the point of input has to move forward in exactly the same manner that it would move for a larger load; this in turn has exactly the same effect as regards the primary power factor as an increase of the load, and it may either increase or decrease this power factor according to whether the machine is already lightly or approximately fully loaded. If lightly loaded, the effect would obviously be to increase the power factor, but of course that is one of the worst methods of doing so. I think the complication of the cascade motor is more apparent than real, and is due to our being less familiar with this machine than with, say, ordinary continuous-current machines. I am not, however, a great believer in simplicity as the measure of fitness of a machine; what we require in a machine is that it shall be more fit than its predecessors for the end desired.

Mr. Ingleby. Mr. J. C. B. INGLEBY: In view of there being such a multitude of closed and paralleled circuits all round the stators and rotors of these motors, would not a difference in the length of the air-gap—say, caused by wear of the bearings—have a tendency to create excessive heating or serious out-of-balance currents locally on the stators or rotors? It would be interesting to know whether the relative magnetic flux density in the stator and rotor teeth, in respect to the density in the air-gap, is of great importance in choking down such out-of-balance currents.

Mr. Hunt. Mr. L. J. HUNT (*in reply*): Dr. Pohl objects to the use of cascade windings for a constant-speed motor, and his criticism in the main consists of a comparison of the cascade with the squirrel-cage motor, much to the advantage of the latter type of machine. In writing this paper I have endeavoured to point out the various classes of drives for which in actual practice the cascade motor has proved its superiority. It has never been suggested that this motor meets every case, and where the conditions permit of the use of squirrel-cage motors it would be folly to consider any other type. But much has been done to

* J. S. NICHOLSON and B. P. HAIGH. "A Single-phase Motor with Pole-changing Windings." *Journal I.E.E.*, vol. 50, p. 268, 1913.

Hunt. discredit this extremely useful machine by the reckless way in which it has been installed, often to meet conditions for which it is entirely unsuitable. We can all probably recall instances where squirrel-cage motors have been installed to drive machines the starting conditions of which have been very severe, resulting in difficulties and serious trouble. I can recall an instance of this where large squirrel-cage machines were installed for driving air compressors. The machines were quite incapable of accelerating under load, and the compressors had to be started by admitting air to the cylinders. Needless to say, all the rotors had to be removed and new ones with slip-rings installed instead.

Winding diagrams necessarily look complicated, and those of the cascade machine are no exception to the rule, but there is a considerable difference between the finished windings and the paper representation of them. The actual machines are extremely simple and there is not on record a single case of any of these one-speed rotor windings breaking down from electrical causes. It may surprise Dr. Pohl to hear that as the result of practical experience these machines are being exclusively used in a large number of installations where high-speed machines could have been used at a considerable saving in initial outlay.

It must be borne in mind that, owing to the large number of parallel paths in the rotor windings, the maximum possible voltage is very small, and a further advantage is obtained by the self-balancing effect of this construction. In order to investigate this property, tests were made some years ago, first with a series coupling of the rotor windings and afterwards with parallel connections, and it was found that owing to the automatic balancing obtained with the latter, the magnetizing current and the no-load watts were quite appreciably reduced. The suggestion made by Dr. Pohl, that a single-speed motor might run at 50 per cent above its proper speed if a short-circuit occurred in the rotor, is very interesting, and at first sight there might appear to be something in it, but he has overlooked the fact that the omission of certain of the rotor bars renders it absolutely impossible for the current distribution to become uniform, the condition necessary for super-cascade speed. As a matter of fact it is extremely difficult to detect a short-circuit in the rotor windings unless a motor be allowed to stand for quite a considerable time with full voltage on the stator. On one occasion a motor went through all its tests perfectly satisfactorily, and it was not until a final trial was made, with the rotor standing for some time, that it was found that a short-circuit caused by the presence of solder had existed whilst all the tests were being made.

Dr. Pohl criticizes the parallel-connected stator windings, and is under the impression that they must require twice as many wires as a series winding for an ordinary motor wound for the same speed. He has, however, overlooked the fact that a 12-pole cascade motor is wound for only 8 poles. With regard to the question of power factor, the cascade machine has a distinct advantage over the one-field machine, especially when wound for very low speeds. It should be pointed out that all the machines described in the paper have completely open slots. If they had semi-closed slots very much higher figures could be obtained. Cascade motors with semi-closed stator slots are being built by Continental makers of these machines.

I much value Dr. Pohl's opinion as regards the suitability of these machines for driving winding engines. Results already obtained are very encouraging, and in a few weeks test figures will be available on some large winders that have recently been started up. Mr. Hunt.

I am surprised that Dr. Pohl does not consider these machines suitable for driving colliery fans, because in this connection and in the driving of air compressors the multi-speed motor has met with considerable success. The horse-power required to drive a fan falls rapidly with the speed, and that is the reason for operating the motor in mesh for full speed and in star for cascade speed. This change in connections gives a much reduced magnetic flux in cascade, so that a standard slip-ring machine may be employed without fear of over-saturation of the iron at cascade speed. The difference between a two-speed fan motor and a standard slip-ring machine is only a change in the end connections. The arrangement suggested by Dr. Pohl would be much more expensive, occupy more space, and be more complicated.

I now come to the question of inching, and I have no doubt that Dr. Pohl can obtain by very careful design excellent properties with a one-field motor. I am constantly hearing that manufacturers will not guarantee very low-speed running with slip-ring machines; and to illustrate this it is only necessary to mention that at the present time cascade motors are being installed in a steel works in Sheffield for the operation of steel converter plant, where it was originally intended to use slip-ring machines running at 750 r.p.m. After seeing cascade machines running at creeping speeds the engineer decided to change his gearing and install machines of this type wound for 500 r.p.m.

Mr. Wright referred to the application of these machines to marine propulsion. A good deal of consideration has been given to this subject, but time has not permitted of any experimental work. It is not at all difficult to design alternators for two numbers of poles in the ratio of 2 : 1 : and with such a machine and a two-speed motor, propeller speeds can be obtained in the ratio of 6 : 4 : 3 : 2 and all the starting can be done by means of slip-ring resistances.

The stator slots of all the motors described are of the completely open type without any form of magnetic bridge, and the rotor slots are of the semi-closed type. The stator coils are former wound.

In reply to Mr. Creedy, patents have existed for some years for the application of the single-core cascade principle to machines having commutators, but the development of the induction type of machine has occupied all the available time.

Mr. Burnand referred to the application of pole-changing arrangements to squirrel-cage motors for starting purposes. A motor of this type was developed in 1903 and 1904 and has a high-resistance squirrel-cage winding to which is connected, at certain points, a low-resistance ring. This machine is fully described in the 1910 edition of Mr. Hobart's book entitled "Electric Motors." Machines of this type proved quite successful and will start a load with considerably less current than ordinary squirrel-cage machines.

Mr. Ingleby raised the question of out-of-balance currents due to the parallel connections of the windings. As has been explained in replying to Dr. Pohl, these parallel con-

Hunt. nections enable the motor to operate satisfactorily even when the rotor is very badly out of centre. In each phase of the stator winding the two parallel paths are interconnected at three points; this feature gives the winding great flexibility. Mr. Ingleby also asked a question as to the comparative weights of a cascade machine and two separate machines connected in cascade. In the case of fan driving, the weight of the two-speed motor would be the same as that of the first machine of the separately connected cascade set, so that the weight of the latter would be that of the two-speed motor plus that of the second machine. Mr. Hunt.

DISCUSSION ON

"BRITISH PRACTICE IN THE CONSTRUCTION OF HIGH-TENSION OVERHEAD TRANSMISSION LINES." *

SCOTTISH LOCAL SECTION, 3RD FEBRUARY, 1914.

Mr. D. M. MACLEOD: The author has done well to call attention again to the unsatisfactory position of the law pertaining to the erection of overhead lines by electric supply authorities. As matters now stand, the delay in getting an overhead line approved is a most serious handicap to power development. Wayleaves have to be arranged with the ground superiors and permission obtained from the agricultural tenants, and plans and specifications have to be issued to the Postmaster-General, the Board of Trade, and the local authority; five parties have thus to be satisfied before the work becomes an accomplished fact. In my opinion the requirements of the Board of Trade and the Postmaster-General could quite well be met by the issue of suitable regulations, specifying the requirements of the two departments and framed on similar lines to those recently issued by the Home Office. In addition to this, detailed constructional plans that have been approved and certified might be held as evidence of the consent of the above departments, and as such could be submitted to the local authority; such plans could be approved for a period of five years unless revoked earlier. It seems unnecessary that the same formality should have to be gone through for every new line. It is particularly gratifying to note Mr. Trotter's remarks with regard to carrying overhead lines by the side of public highways. These remarks augur well for the relaxation of the stringency of the Board of Trade Regulations dealing with the angle at which a public highway may be crossed. In some cases it is necessary to use underground cable for road crossings on account of it being impracticable to meet the conditions for an overhead crossing. I wish also to endorse the author's remarks as to the importance of carefully surveying and setting out a line. In my opinion the success of an overhead line depends almost as much upon its position as upon its construction. Due allowance must be made for the fact that in the United Kingdom the prevailing wind in stormy weather is south-westerly in direction. If through ignorance or neglect of this fact an engineer builds a line immediately to the north of a tree or plantation, the first gale will cause small branches to be detached from the swaying trees and carried sometimes 15 or 20 yards until they fall across two or more of the conductors. This factor is so important, not only from a supply point of view but also from a public safety standpoint, that it ought to be laid down as a standing regulation that no high-tension line should be carried past the north side of a tree or plantation at a less distance from it than 40 yards.

Reference is made in the paper to the split-conductor system. It seems to me that this system as applied to overhead construction has very little to commend it, for the very simple reason that for a given total sectional area of line twice as many insulators have to be used as if only one circuit were employed. I think it will be conceded that the insulator is the weakest part of overhead construction; if that is granted, then doubling the number of insulators doubles the risk of failure. If I correctly understand the Merz-Hunter system, the failure of one line causes both circuits to be automatically made "dead." For three-phase overhead construction I am of opinion that a single set of conductors with Merz-Price balanced protective gear employing bare pilot wires requires a lot of beating. With reference to the author's suggestion to use insulators of different colours for each circuit, I am not sure that there is much need for such discrimination, as it seems to me to be inherently bad practice to attempt to carry more than one circuit on any given pole line on account of the great risk of fatal accidents. The colour which is found to attract least notice from wayfarers is dark brown. It is only necessary to look at the condition of some of the Postmaster-General's white porcelain insulators to be convinced that white is a colour to be avoided for high-tension transmission-line insulators. I understand that celluloid envelopes for attachment to the top of insulators are largely used all over the Continent. In actual practice it is a matter of great difficulty without some such device to locate punctured insulators, as testing appears to show that the line is in good condition. In wet weather particularly, even a sound line seldom shows more than a few hundred-thousand ohms insulation resistance. With the provision of a celluloid cap fitting tightly round the neck of the insulator, as soon as an insulator fails the celluloid cap is burnt. For a while the Clyde Valley Electrical Power Company were very much troubled with punctured insulators; it was found by careful observation that the cause was due to unequal expansion in the insulator itself. After a spell of warm weather, when the long

* Paper by Mr. B. Welbourn (see pp. 177, 217, and 302).

leod. channel arms were exposed to the sunshine of a hot day, it was found that the heat was conducted from the arms by the steel pins to the inside of the porcelain, which was thus maintained at a high temperature. When a cool breeze arrived, internal stresses were apparently set up, and it was only a question of time before fissures began to develop in the insulators, eventually leading to a failure. We have had as many as six punctured insulators over a length of one mile. It would naturally be expected that warm weather would be particularly favourable to overhead transmission, but this is only so when suitable provision is made for dissipating the heat from the sun-baked ironwork. Experience goes to show the wisdom of making the cross-arm construction as light as possible, consistent with mechanical strength ; and the use of reinforced wooden insulator-pins are found very effective in arresting the conduction of heat to the inside of the porcelain. I am rather surprised to observe that no reference is made to trouble arising from birds settling on overhead lines. The terminal pole arrangement shown in Fig. 12 is one which seems liable to disturbance from birds settling on or about the choke coils. On the lines for which I am responsible the bird trouble has been effectually overcome by the use of treble insulation on all terminal and turning poles.

Seddon. Mr. E. SEDDON : The reason for our lack of knowledge on this subject is probably due to our natural and abundant coal resources, together with the densely populated towns which have contributed largely to our placing stations just where the supply of electricity was required, and consequently there has been practically no alternative but to develop the underground cable system. Engineers abroad had to face a different position, as most of their power resources were in another form and far away from the area of supply. Consequently, the overhead system appeared to be the only practical method of transmission, so that all our early information on the subject was imported. But now we are collecting data of our own from British experience, and if we are to realize in practical form such a scheme as that outlined by Mr. McWhirter for utilizing the series of lochs between Fort William and Fort Augustus, we shall then no doubt have a transmission system that will rival those on the Continent. In comparing the relative costs of the two systems, the author has probably been a little conservative with his figures for cables. When a new cable route is commenced there is the temptation to lay down many more ways than would be required in the immediate future : also, large street boxes are built to accommodate all the future cables. This extra expense is idle capital for many years, although of course it may prove a good investment later as the business expands. I see that no reference is made in the paper to reinforced concrete poles. Are these unsuitable because of the electrolytic corrosion that is likely to occur and cause cracking ? I should like to ask the author what objections there are, if any, to earthing one phase of the line. It seems to me this would considerably cheapen the construction, as only two insulated wires would be required and the earthed line wire might then take the place of the ordinary earth-wire. Perhaps there are Board of Trade objections to this procedure. With regard to arresters, I have had experience with the aluminium type and I consider it a very reliable piece of apparatus. In positions where persons are more or less in constant attendance, the daily charging of the arrester is not a very troublesome operation. There is the advantage that the horns are cleaned of dust at the time of charging. For station use it is desirable to have some device fitted to give an alarm each time that the arrester operates, so that the time of each discharge can be recorded—this time might be found to coincide with some fault on the system. Mr. Seddon.

Mr. Robertson. Mr. J. A. ROBERTSON : I should like to ask the author whether the estimate on page 178 is for underground cables laid solid or drawn into conduits. I made an estimate recently for a similar size of cable at 10,000 volts, and the price for underground work varied from £1,150 per mile for laying direct in the ground to £1,850 per mile for drawing in fibre conduits. We adopted the latter system as immediate economy was not of primary importance. The cost of an overhead line for the same duty amounted to £620 per mile exclusive of wayleaves, which I understand the author has capitalized in his estimate. I am pleased to note that he has not joined in the criticism (much of it ill-informed) which has been levelled at the Board of Trade in recent years. I agree with Mr. Trotter that the Board of Trade Regulations are really a record of the best practice, and I think it is general experience that the Board is always ready to consider new circumstances as these arise. No doubt it would be convenient to have a standard system of overhead construction as pointed out by Mr. Macleod, but it is extremely difficult to say how such a system could be devised in view of the rapid development in appliances and methods of construction. I should also like to ask the author whether he can explain the curious fact brought forward in the London discussion : that snow does not accumulate on overhead aluminium conductors while current is passing through them. I have heard it suggested that oxide of aluminium is a non-conductor and that the effect is due to electrostatic causes.

Mr. Welbourn. Mr. B. WELBOURN (*in reply*) : In reply to Mr. Robertson, the figures on page 178 are necessarily representative of the general case. They were taken from actual contracts which in my opinion represent average conditions. The cables are armoured and laid direct. The cost of the overhead line does not include the capitalized value of wayleaves, and it is perhaps higher than in the case cited by Mr. Robertson, because a lead-covered telephone cable is included. With regard to the behaviour of aluminium in a snowstorm, there is an extraordinary divergence of opinion. Some Canadian engineers are emphatic that aluminium does not gather snow ; but I know that on an aluminium line in this country sleet and snow did collect. I think that experiments on this subject should be made with both old and new copper and aluminium wires, and there is reason to think that the matter will soon be cleared up by independent investigators. I was pleased to hear the remarks in support of the factors of safety prescribed in the Board of Trade Regulations.

In connection with Mr. Macleod's suggestion of obtaining rules from the Board of Trade to cover all lines to be constructed during a period of five years, I think it might be rather unwise, in view of the number of changes that take place, to tie one's hands for five years. In five years we have got away from the complicated cradle-guards required by the Board of Trade, and in another five years we may have done away with guard wires altogether. As

Mr. Welbourn. regards the split-conductor system, it is quite true that the parallel circuits are both shut down in the event of a fault, but actually they should be considered as one circuit. I have seen and heard about the celluloid caps for insulators, but I do not know of a case in this country where they have been used. It is probable that Mr. Macleod's trouble with burst insulators would disappear if he would adopt heavy twine packing when fixing the pins. This would allow for the expansion of the pins and insulators. With reference to reinforced concrete poles, so far as I know these have not been used on high-tension lines in this country, but I know of two low-tension lines where they are used. One of these is in a chemical works where neither wood nor steel would stand, and the results have been good.

The question raised by Mr. Seddon of earthing one phase of a three-phase line has been discussed, but I do not think the system has been adopted. I see no reason why one phase should not be earthed so far as overhead construction is concerned, but in order to avoid disturbances of G.P.O. and other circuits the earth-wire would have to be insulated at all points except at the alternator or transformer. In ordinary circumstances the insulation of the earth-wire need not amount to much, but such a wire may be called upon to carry a high voltage in an emergency. On the other hand the insulation of the other parts of the circuit, such as cables, transformers, etc., would have to be designed to withstand the pressure between the phases instead of between one phase and earth. This is probably the reason why the method has not been adopted.

Western Local Section, 16th February, 1914.

Mr. Allan. Mr. C. T. T. Allan: The author has referred to binding where the lines are on level ground, but makes no mention of binding on steep slopes. There are some cases in South Wales where the gradient is 1 in 3. With ordinary side binding the conductor will rest on the top shed, owing to the slope of the hill. For level country we use the ordinary Post Office side binding with chafer wire; and for slopes we rest the conductor in the top groove of the insulator and bind it in with strands of the line wire, which are secured at each side by Crosby clips costing about 1½d. each. We have had no trouble whatsoever with these two binders. I should very much like to have the author's views on the position of the earth-wire. American engineers place it above the conductors, while we for other reasons put it below. Which is the better position in relation to atmospheric disturbances? We know that where it is over the conductor it should in general be of the same metal as the conductor. For some three or four years past we have been experimenting with iron choke coils. I think they have some value. On several occasions when the consumer's protective and other apparatus has been destroyed in a thunderstorm, the power company's apparatus has not been affected, with the exception of the current transformers on the meters. From this it would seem that a cheap choke coil is a current transformer. I noticed that in the earlier discussions of this paper it was stated that to prevent damage to transformers it is well to insulate the last turns extra heavily. We have found that even with this arrangement transformers have broken down, and the whole transformer has had to be sent away to the makers for repair. Would it not be cheaper to provide the extra heavily insulated turns in a separate tank outside the transformer and so avoid the necessity for sending away the whole transformer when a breakdown occurs? We have tried the permanent leak type of arrester, the horn type, the usual multiple-gap, and the electrolytic type, and we have experienced more trouble with than without them. For a wooden pole line it is usually specified that all cutting for cross-arms, etc., shall be done before creosoting; but after erection climbing irons form innumerable rain pockets which surely will tend to rot the pole. We avoid this by fixing round section iron pole steps, costing 1d. each, when erecting the pole line. The first step is above the barbed wire coils. To reach it the patrol man carries a very light 10 ft. 10 lb. ladder. Instead of riveting the earth-wire to the earth-plate, we usually unstrand the earth-wire, spread it, and run the cast iron forming the earth-plate round it. It is well I think to procure the best insulators that one can and to pay a good price for them. It is cheaper in the end. As regards the speed at which a repair can be effected, pole lines have the advantage as against a cable. On a Sunday, 12 miles from the base, a bird caused a pole-line insulator to break down. Within 3½ hours the line was repaired and alive again. Pole-line troubles as a rule are very few. After our first pole line was made alive the daily average of birds killed was rather high, but after the first month the average was reduced to one or two per month. The birds seem to have become educated, because on pole lines subsequently made alive there have been scarcely any bird casualties at all. Our chief trouble is malicious damage. A police court prosecution, however, usually cures this. Both malicious damage and wayleave troubles are to a great extent remedied by high poles and long spans. A rifle is needed to break the insulator on a high pole, and with long spans where the line crosses arable land the poles can generally be fixed at the hedges. This method is of further benefit in reducing the number of insulating points. It is especially adapted for the South Wales hilly districts, particularly in crossing narrow and rocky valleys. Our longest span in a case such as this is about 1,500 feet. I quite agree with the author that telephones should not be run on the same poles as power wires. I am of opinion that they, as well as duplicate pole lines, should be on separate poles, and if possible by separate routes. In Stockholm there was considerable trouble where telephone lines were run on the same poles as the live conductors of the single-phase railway. Our telephones are always run by a separate route, and we usually have the use of them when most wanted, namely, during breakdowns. I should like to mention that the well-remembered local tornado a few months ago caused no damage to our high-tension pole lines, one of which was at right angles to its path, although houses two hundred yards away had the roofs and windows wrecked.

Mr. Bamford. Mr. H. M. Bamford: From my experience of pole lines I consider the use of steel poles and long spans is almost

ford always preferable. The cost of maintenance is somewhat higher than that of wood poles, due largely to inefficient painting, but this is partly counterbalanced by fewer breakages of insulators. Too much care cannot be taken with the paint and its application; for if applied over rust or dirt, as I have seen it, satisfactory results cannot be expected. Even in a wood pole line it is generally necessary or advisable to use iron fittings, which are greater in number and also affect maintenance. With regard to the author's remarks on creosote, I have frequently noticed when lifting poles, in clayey ground, a quantity of creosote at the butt, generally two to three pints.

tor. Mr. C. F. Proctor: On the question of wind pressure, 25 lb. seems to be abnormal. I have heard of cases of 18 lb. to the square foot with a very high structure, and in one exceptional case it was 22 lb., but only for one foot, and on erecting a big shield 25 ft. square the mean wind pressure was reduced to about 18 lb. per square foot. I think the real trouble is the question of snow. It seems to me that we should not fix a certain distance and a certain wind pressure, but consider each neighbourhood on its merits: for instance, what is correct in Wales cannot be so on the North Coast where we get heavy snowstorms and clinging snow. With regard to the author's remark that on live aluminium wires the snow has been found not to stick, is it owing to heating of the wire? I think this has been found to be the case on several overhead lines. We have seen snow sticking to telegraph wires, and not so much on transmission wires. I have found aluminium very liable to crystallization after a time. I do not know whether this is purely a question of the purity of aluminium; motor-car builders, however, do not trust aluminium unless it is abnormally thick. I should like to ask the author whether old wires turn crystalline and lose ductility.

Lewis. Mr. H. Lewis: Whilst I agree with Mr. Allan that the landlord is sometimes justified in objecting to the ugly creosoted H-poles, which damage the grass and kill his cattle, and for which he only gets a nominal remuneration, yet this does not apply to the Urban, Rural, or District Councils. From my point of view, they are the worst offenders: they constantly refuse even to consider the question of overhead lines being erected in their districts, although the ratepayers will materially benefit by being able to obtain electrical energy; and if they do consider the matter they impose such obligations as to make the line almost as expensive as laying the cables underground. I think the Board of Trade should, in the interests of the statutory undertakers and the ratepayers, consider on its merits each application for the erection of overhead wires and have the right to dispense with the consent of the local authority, if it think fit. I quite agree that the Board of Trade is right in adhering to the regulations concerning the factors of safety, but I am of the opinion that there are cases in some of the side streets of a town where these regulations might be slightly relaxed.

essor on. Professor F. Bacon: On page 178 the author gives a table of costs. I gather from his remarks that he concludes from that table that the cost of underground cables compared with that of overhead lines is proportionately greater the higher the pressure, and also proportionately greater the larger the number of kilowatts conveyed. I do not quite see how the table brings out this second fact, viz. that overhead lines become cheaper in comparison with underground cables the larger the power transmitted, the pressure of transmission being the same in each case. Next as to the wind pressure, previous speakers have commented on the high values mentioned: but the method of calculating the effective area exposed to the wind pressure seems to me quite as important as the actual value assigned to the wind pressure itself. I notice that 0·6 times the diameter is taken as the effective breadth. I should like to know how the coefficient 0·6 came to be adopted. The problems presented by aeroplane construction have led to so much research on the wind resistance of wires that more precise information ought to be available than formerly, and I think we might expect to find that instead of employing 0·6 in all cases it would be more correct to vary the coefficient according to the diameter, possibly also according to whether the line was a stranded cable or a single solid wire of the same overall diameter, though I must admit this is rather splitting hairs when there may be snow on the wires increasing their diameters by many hundreds per cent. Professor Bacon.

I was very interested to hear what the author said about the mechanical testing of materials. I entirely agree with him that the stress allowed in a wire should be based upon the elastic limit, meaning thereby the limit of proportionality of stress to strain. I am afraid, however, that the fixing of the limit of proportionality is apt to be much influenced by the sensitiveness of the extensometer employed; though perhaps this difficulty is not so strongly felt in the case of hard-drawn wire which can be tested in long lengths. In the case of wrought copper it is exceedingly difficult to decide at what point on the stress-strain curve the proportionality ceases. In fact, in the case of soft annealed copper and certain other alloys which behave in the same way, I think there is absolutely no limit below which it is safe to say a strict proportionality exists. With regard to the use of aluminium in place of copper, I should like to ask for information as to the possibility of using certain rich aluminium alloys that are stronger than pure aluminium. I have tested mechanically a number of these alloys—duralumin in particular—and have been impressed with the apparently excellent results that can be obtained. Is it that the small amounts of magnesium, iron, zinc, etc., which are added to aluminium to increase its mechanical strength spoil the electric conductivity to an extent which makes the metal commercially unsuitable for transmission lines, and is there no prospect that an alloy of aluminium will be found stronger than aluminium itself, but not materially higher in specific resistance? I should also like to ask the author whether he thinks it necessary to test his finished cable after it is stranded as well as the individual wires. I know it is a difficult job to obtain a really satisfactory tensile test of a stranded cable, and if it has once been conclusively shown that no useful purpose is achieved by making such a test, perhaps it is better omitted.

Mr. T. Schontheil: I quite agree with what the author has said about wayleaves. In regard to his remarks as to the evident heating of stranded aluminium conductors, it seems to me that this may possibly be due to a cause which I think is well known, *i.e.* that in drawing aluminium a skin forms on each wire, such skin being a partial dielectric. The author mentioned that interest Mr. Schontheil.

Montheil. has been taken in poles creosoted by the Rüping process. I believe this is the process by which the poles are creosoted and then de-creosoted as far as possible. It seems to me that by this process the advantages of the creosoting are taken away, especially that advantage to which the author referred—that in the ordinary way the surplus creosote runs down to the earth line and protects the pole. The greatest deterioration of poles undoubtedly takes place at the earth line, and I should like to suggest an additional means of protection. This consists in covering poles with a collar of concrete extending about 18 in. to 2 ft. below the earth line and about 4 in. above. This has been tried with excellent results. With regard to the continuous earth-wire, the author did not state whether the earth-wire that he refers to is of steel or copper. As far as I know, copper is far preferable. Perhaps he would give his opinion on that point. Reverting back to the question of poles, one drawback to the use of steel poles is that corrosion takes place inside more than outside. If a steel pole is properly coated—when it is as free from rust as possible—with a good quality paint and repainted at proper intervals, I do not think much deterioration will take place outside, but certainly it takes place inside, and it is practically impossible to get at that corrosion. I understand that in America steel tramway poles have been filled with reinforced concrete with very good effect, and no doubt something like that will have to be done here. Some of our tramway poles, such as those on the first electric lines in Dublin, Bristol, etc., have been in use for 10 to 15 years, and no doubt a very large amount of corrosion has taken place inside the poles, or rather on the inside surface of the poles. The author suggested that a better plan than that of erecting H-poles to carry duplicate overhead lines would be to construct ring mains; that method, however, would lead to additional wayleave difficulties. I think perhaps the better plan is to put the poles alongside, not close together, but a sufficient distance apart, so that if a pole carrying one line happens to be blown down, it will not foul the other line. I think this plan has been adopted in some cases. The author seems to advocate rigid binding, but I think he has overlooked one great disadvantage of this method. If a conductor should break, the strain has to be taken up by the adjacent insulator pins, which in all probability would not bear the strain; whereas if an ordinary more or less loose method of binding is used, the conductor in a case of breakage simply slips through and does no damage to the adjacent insulators or insulator pins. With regard to the reinforced system of crossings, I understand that the Board of Trade does not require a guard netting underneath, but is quite satisfied, as are also most railway companies, with merely the reinforced system.

Mr. Welbourn. Mr. B. WELBOURN (*in reply*): The point which Mr. Allan raised in regard to the binding in of insulators on slopes is not a difficulty that many engineers have to contend with. I have never had to deal with a line such as he mentioned. He also referred to the position of the earth-wire. I think that is a matter everybody must decide for himself. It seems to me that lightning is not sufficiently frequent in England to justify the placing of the earth-wire above the power line. There have been cases where the continuous earth-wire has broken, fouled the power lines, and interrupted the supply. Not only so, but if an earth-wire which has been properly earthed does fall and the protective gear does not operate sufficiently quickly, the power wires probably get burnt, so that these have also to be renewed in at least one span. I have discussed this matter extensively with Canadian engineers and I have found that considerable difference of opinion exists. One engineer told me that he had tried his earth-wire in both positions, but that he certainly favoured the position below the power wires. The chief use of the earth-wire in this country is not to protect lines against lightning, but to connect all metal-work on the poles and afford a sure method by which it can be earthed. Another advantage of having the continuous earth-wire below the power lines is that if it is desired to carry on the line a lead-covered cable, it is there ready for the work. I think one speaker misunderstood me with regard to the material to be used for the earth-wire. I stated quite clearly on page 188 of the paper that the earth-wire should undoubtedly be of the same material as the power line, or of bronze; it certainly ought not to be of galvanized steel, which would have a shorter life.

I was very interested in Mr. Allan's experience regarding the insulated turns of transformers. The arrangement referred to in the paper is of course cheap. No noticeable increase in the cost of these transformers over that of the old arrangement is seen from tenders recently received; and this is the main thing. I believe that I am correct in stating that not one of these specially insulated transformers has ever been known to break down in this country on account of lightning. I know of one or two lines where insulated coils are placed outside the transformer, but this arrangement entails difficulties in sub-stations in finding room and connecting up.

I was pleased to have Mr. Allan's confirmation of the difficulties that have been experienced with nearly all types of arresters. I have definitely come to the conclusion that there is not an arrester at present obtainable which is entirely satisfactory for *all* conditions, although the Moscicki condenser deals satisfactorily with high-frequency disturbances and reduces the potential gradient of a surge.

The difficulty of tearing the poles on account of linesmen going up and down with climbing irons, is one which is being much discussed, and in some districts ladders only are used. I know many engineers who will not permit linesmen to use climbing irons, but the expense of carrying ladders is very serious. Mr. Allan's combination of pole steps with a light ladder is excellent.

With regard to insulators, I agree with Mr. Allan that the best should be used. It is only a question of a few pounds' extra cost; and the gain when the best are secured is very great. I have said in the paper that attention should be paid to detail. This is one of those details which I had in mind. There is no doubt that money spent on good insulators is well spent.

I have been surprised to notice that in all the discussions only one speaker has mentioned the colour of insulators. Possibly the way in which insulators are shot at may be due to their colour. On some lines where white ones are used, they are a target for every mischievous person in the district.

The matter of wayleaves has formed a striking feature in these discussions, and I hope it will be dealt with by the Institution.

bourn. Mr. Allan also referred to the question of factors of safety. There has been no request in any of the discussions for any further reduction in the factors of safety. The attitude of the Board of Trade in regard to wind pressure is not quite clearly understood. Mr. Trotter has a collection of wind-pressure records which he would place at the disposal of any members who would like to consult them in London. There are many localities where a pressure of 25 lb. per sq. ft. is never reached, 17 lb. usually being the limit. In all cases where the former pressure has never been recorded, Mr. Trotter is quite willing to allow the lines to be designed so as to meet the highest recorded wind pressure.

With regard to Mr. Proctor's point about wind pressures, not only is there much information gathered by the Meteorological Department available, but the National Physical Laboratory has carried out extensive tests, which I hope will shortly be published. There is much evidence to show that if the wires are arranged in a horizontal plane, the resultant total wind pressure on the structure is less than if they are arranged in a vertical plane.

In regard to calculating the effective wind pressure, 0·6 of the diameter is the figure given in the Regulations of the Board of Trade, and 0·66 in those of the Post Office. The question of which may be correct is not very material on account of snow loading. The moment that any wire begins to collect snow it becomes a snow rope, which continues to load indefinitely. I know of a case where telegraph wires were loaded to a diameter of 2 in. No overhead line can be expected to withstand such conditions if erected on a commercial basis.

Mr. Bamford's point about painting has been referred to in what Mr. Wigham said in his communication to the London discussion. He says that on the steel lines which he has erected in Cornwall the question is highly important because of the salt-laden atmosphere, and that he has found Dixon's graphite to be superior to all the so-called bitumen paints.

The question of the crystallization of aluminium is, I think, one of purity of the metal and its proper annealing. I have never encountered a bona-fide case of crystallization when aluminium of at least 99·30 per cent purity was used. I have certainly met with cases of failure of so-called aluminium castings, but in every case there was considerable admixture of alloys.

Mr. Lewis went far in confirming my introductory remarks, viz. that much low-tension work must be considered very carefully in regard to the question of cost (*i.e.* in deciding whether overhead or underground cables should be used), especially where wayleave difficulties and the requirements of local authorities have to be borne in mind.

Professor Bacon referred to the cost table on page 178, from which it is certainly apparent that for practically the same capital cost in overhead lines three times the number of kilowatts can be transmitted at 20,000 volts that can be transmitted at 6,000 volts, and that compared with underground cables the savings are, at 6,000 volts, approximately in the ratio of 1 to 1·5, and with 20,000 volts of 1 to 2·2, neglecting the capitalized value of wayleaves. Mr. Welbourn.

Professor Bacon also dealt with a very interesting point, viz. the limit of proportionality, and the difference between stranded and single wires. I have examined this question during the last three weeks, and although the experiments have not gone very far, they tend to show that a stranded conductor of aluminium has a limit of proportionality about 3 per cent higher than that of a single conductor. Measurements are about to be made by the National Physical Laboratory so that the results should be generally acceptable.

The question of aluminium alloys on overhead-line work is not only one of specific resistance, but mainly one of corrosion. I am satisfied that no aluminium alloy can be obtained, which if not protected from air and moisture will not fail due to local electrolytic action. Experiments have been carried out in this connection and the results are so conclusive that I would never recommend the use of aluminium alloys for an overhead line.

Mr. Schontheil referred to creosoting by the Rüping process. One of the valuable points raised in this discussion was the statement by Mr. Stubbs that poles so dealt with can be painted. He said that experiments are now being made between Messrs. Richard Wade, Sons & Co. and the Post Office Engineering Department to find the best mixture to use for this purpose.

Mr. Schontheil also dealt with the question of protecting the poles from the action of wind and water at the ground line. On page 184 of the paper particulars are given of a mixture with which I have had some experience, and perhaps if Mr. Schontheil has a case in mind he would like to try it.

I am familiar with the method of filling tubular steel poles with ferro-concrete as used in America. It promises to give satisfactory results.

Referring to the question of binders, I think that flexible binders such as I have shown here to-night will not allow the conductor to slip through if a line wire breaks. It is rather more likely that the binder will slip round the insulator and so relieve the strain. I think the Board of Trade will now permit suspension guards to be used without cradling below, and it is only sentiment which causes the flat guard below the wires to be retained.

Further Contributions to the Discussion.

thal. Mr. A. W. Isenthal (*communicated*): With regard to the use of the Moscicki condenser as a separate system of protection, I have carefully read the remarks of speakers at the various Local Section meetings, and have gained the impression that one of the most essential reasons for the adoption of such condensers has been entirely overlooked: I refer to the effect of the condenser on the potential gradient of the surge wave. For instance, in the discussion before the Newcastle Local Section* Mr. Hunter agrees that in so far as the Moscicki condenser does away with the spark-gap it must be an improvement on other types. This goes of course to the very root of the matter; but he discounts this very great advantage of this type of arrester by expressing the opinion that the apparatus would become very large and expensive if it had Mr. Isenthal.

* Page 302.

Mr. Rosenthal.

to dissipate the surge energy. This does not go quite as far as the objection raised by some early opponents of the system, who maintained that the condenser could not dissipate any energy at all; but the fact is—as Professor Petersen, among others, has shown—there is no need whatsoever to dissipate the energy of the surge in the condenser. Its legitimate function in the case of protection is partly to reflect the incoming surges upon the line, where their energy will be rapidly dissipated, and also (and this is the more important part) considerably to lessen the steepness of the incoming wave fronts, or, in other words, to reduce the potential gradient of these surges. By far the larger number of defects that can be traced to surges of this character are due to the abnormal potential distribution in the windings of generators and transformers brought about by the steepness of these surge waves, and are not the consequence of the absolute voltage excess produced by such surges. Now, it has been shown that a comparatively very small capacity is capable of bringing about a flattening of these potential fronts quite sufficient for all practical purposes, and beyond a certain minimum size (which is dictated by other considerations) the protective condenser battery is quite independent of the amount of energy that is transmitted over the line.

Many speakers have recorded their conviction that spark-gaps should be avoided; but this is a generalization that is likely to be misleading. The destructive effect of surges may be due to two causes, according to the nature of the surges. There are the surges which are either of a high-frequency nature, or which travel along with very steep wave fronts, and in both cases a spark-gap would certainly be not only a possible source of new surges, but also entirely useless, because the amplitude of the surge voltage may conceivably be such that no spark-gap (which is set at a voltage higher than the working voltage of the line) would be bridged, and only the abnormal potential distribution introduces danger to the plant. There are other surges which are characterized by an actual, and sometimes very considerable, rise of pressure at a more or less normal potential distribution. This class of surges can only be dealt with by providing suitable gaps between the line and earth, but—and this is important—it is difficult to construct a gap which does justice to two very conflicting conditions, *i.e.* that it should permit a sufficient amount of energy to pass off in the shortest possible time, and yet that its total resistance should be sufficiently high to preclude the generation of oscillatory discharges when operating. The majority of gaps in actual use are either apt to produce new surges of an oscillatory and therefore highly dangerous nature, or the resistance which has to be placed in series with them is so high as to make the efficiency of this "by-pass" very questionable. Dr. Garrard, in the course of his remarks at the Birmingham meeting,* mentioned this matter, and referred to the Giles valve, which has been shown in practice to be a satisfactory solution of the conditions governing the design of a spark-gap. It then comes to this; that from the very nature of the matter we must have several types of arresters, because it is impossible to expect, for instance, a water jet or an iron-core inductance, which can deal very effectively with static charges, to be of any use in the case of high-frequency surges or switching surges.

* See p. 237.

Mr. A. E. McColl (*communicated*): On page 178 the author has given a table of comparative costs per mile of overhead transmission at pressures of from 6,000 to 20,000 volts to show the small increase in the initial cost due to increasing the voltage. This holds good for what can be classed nowadays as low or moderate-pressure systems, where the length of span, sag, windage, method of suspension, and arrangement of the conductors, are a larger factor in determining the spacing than the electrical characteristics of the air itself. When we come to very high voltages, the strength of the air as a dielectric is the factor that determines the spacing of the conductors—other conditions remaining the same—owing to larger and broader towers and greater wayleave expenses being necessary, and in the case of three-phase transmission at still higher pressures possibly greater separation of the phases on individual towers or poles. The conductor separation is affected by several things, among which are: factor of safety, size of conductor, barometric pressure, and in a lesser degree the temperature. Weather conditions, such as fog, sleet, rain, and snow, all lower the critical disruptive voltage of the system, and increase the loss of power. In a three-phase transmission system where the separation of the line wires is from one-half to one-third of the distance to the ground, the stress at the conductor surface may be with sufficient accuracy stated as— Mr. McColl

$$e = \frac{V/\sqrt{3}}{r \log_e D/r}$$

where V is the voltage between the lines,

D is the distance between the conductors in inches,

and R is the radius of the conductor in inches.

The disruptive gradient of air (R.M.S. value with sine wave) is 53,600 volts per inch with round, smooth, polished wires. A condition depending on the state of the conductor surface lowers the permissible stress that can be reached without power loss taking place in the form of corona discharge. This condition for weathered or roughened wires we may take as 0·95. The above permissible stress holds good for the barometer at 29·92 inches and a temperature of 77° F. The separation of the conductors, D, may be readily found for varying values of the barometer and temperature readings, and factor of safety. Where e is the stress at the conductor surface—

$$e = 53600 \times 0{\cdot}95 \times \frac{17{\cdot}91 \times 29{\cdot}92}{459 \times 77} \times \frac{1}{\text{factor of safety}}.$$

Low factors of safety are taken on high voltage lines; the distance between the phases then becomes

$$\log_{10} D = \frac{0{\cdot}4343\, V/\sqrt{3}}{e \times r} + \log_{10} r.$$

Let us take an example. Suppose the spacing D has to be found for the following conditions: V = 150 kilovolts, $e = 53{\cdot}6$ kilovolts, $r = 0{\cdot}3$ in., factor of safety = 1·1, temperature = 41° F., barometer = 27·5 in.

$$\text{Then } e = 53{\cdot}6 \times 0{\cdot}95 \times \frac{17{\cdot}91 \times 27{\cdot}5}{459 + 41} \times \frac{1}{1{\cdot}1} = 45{\cdot}6 \text{ kilovolts,}$$

$$\text{and} \quad \log_{10} D = \frac{0{\cdot}4343 \times 150/\sqrt{3}}{45{\cdot}6 \times 0{\cdot}3} + \bar{1}{\cdot}4771 = 2{\cdot}2264.$$

$$\therefore D = 168{\cdot}5/12 = 14{\cdot}04 \text{ ft.}$$

Mr. McColl. This distance should represent a possible out-of-phase swing of the conductors. The length of span and amount of sag will increase the above spacing.

On such a system, with the conditions given, the kilowatt loss would be small, although the number of kilovolt-amperes required to charge the line at no load would be large. There would be no loss due to corona, since the disruptive critical voltage (E_c) to the neutral is greater than the operating voltage, these being 95·26 and 86·6 kilovolts respectively, E_c being given by $45·6 \times r \log_e D/r$.

It is interesting to consider the loss which would take place if the line pressure were raised to 200 kilovolts, the transmission length being taken as 200 miles, and the frequency as 25 ∿.

$$\text{Capacity of line per leg} = \frac{0·0388}{\log 168·5/0·3} \times 200 = 2·822 \text{ mfd.}$$

Charging current per phase

$$= \frac{2\pi \times 25 \times 2·822 \times 200/\sqrt{3}}{10^3} = 51·2 \text{ amperes.}$$

Number of kilovolt-amperes required to charge the line

$$= 51·2 \times \sqrt{3} \times 200 = 17,700.$$

Applying Mr. Peek's formula,* the power loss due to corona per mile of single conductor would be found to be 2·411 kw. The total loss would therefore be $2·411 \times 3 \times 200 = 1,446$ kw. No account has been taken here of the progressive rise which would take place along the line if open-ended at the receiving station. Such rise would, especially at the higher frequencies of 50 to 60 ∿, add considerably to the above values of the kilovolt-ampere and kilowatt losses.

The author has stated that the cable makers are prepared to keep pace with the rise in operating pressures in this country. Although it may not be necessary to go to the excessive pressures that are used on some systems abroad, still I think we shall probably be using in the not distant future in connection with railway electrifications alternating pressures of from 50 to 100 kilovolts. Cables for such pressures, and especially for the higher pressure mentioned, will be auxiliary to, and will not supplant, overhead lines. For a large scheme operating, say, a 250-mile transmission at 100 kilovolts, the charging current would be so excessive as to make underground transmission altogether out of the question, especially at the higher frequencies of 50–60. As the mercury converter seems likely to become a serious competitor of rotary converting plant the tendency will be to go above 25 cycles and toward the higher frequencies.

Let us compare the charging currents of an overhead and an underground transmission.

Three-phase overhead lines.

Voltage between conductors 100 kilovolts, *i.e.* 57·8 kilovolts to the neutral.

Spacing of conductors = 10 ft.
Diameter of conductors = 0·4 in.
Length = 250 miles.
Frequency = 50 ∿.

* F. W. PEEK, Jnr. "Law of Corona." *Transactions of the American Institute of Electrical Engineers*, vol. 30. p. 1894, 1911.

Capacity = 3·5 mfd. Mr. McColl.
Charging current per phase = 63·5 amperes.
Capacity of plant required to charge line at no load = 11,000 k.v.a.

Three-phase underground cable.

Each phase to comprise a separate single-phase conductor operating above ground at 57·8 kilovolts.

Diameter of conductors = 0·4 in.
Dielectric strength of insulation = 360 kilovolts per inch.
Specific inductive capacity = 3.
Factor of safety = 2·5.

From the formulæ given above, D = 1·488 in., and the thickness of the insulation = 1·488 − 0·2 = 1·288 in.

The capacity per leg is—

$$\frac{0·0388}{\log_{10} 1·488/0·2} \times 3 \times 250 = 33·4 \text{ mfd.}$$

and the charging current

$$= \frac{2\pi \times 50 \times 33·4 \times 57·8}{10^3} = 606 \text{ amperes.}$$

The capacity of the plant required to charge the line

$$= 606 \times 100 \times \sqrt{3} = 105,000 \text{ k.v.a.}$$

Rather extreme conditions have been assumed, for the purpose of giving more forcible results. More favourable conditions could have been taken for the cable, but they would have rendered its size beyond practicable dimensions. If graded cables had been used, having insulation of varying specific inductive capacity, the results would have been still more unfavourable to the underground system. Of course it is not put forward seriously that a cable system would receive consideration for the foregoing conditions. The comparison is merely intended to show that what is practicable under certain conditions with overhead transmission is impossible with an underground one, as it is not generally realized what exceedingly large plant capacities are required to charge such lines.

Mr. T. S. WALLIS (*communicated*): It may be of interest Mr. Wallis. to members to hear how things are done in Sweden. The supply from the Trollhättan water-power station is at 50,000 volts by overhead lines, and the distance to Gothenburg is approximately 50 miles. From there the energy is distributed at a pressure of 10,000 volts, also by overhead lines where practicable. Our supply at Surte has to return 10 miles from Gothenburg, although the 50,000-volt line passes only about half a mile from these works. I understand that the explanation is that there was already a consumer half-way to Gothenburg before our supply was thought of. The 50,000-volt line runs for the most part on the top range of hills along the coast and is very exposed to the stormy weather that is experienced here. Steel lattice-work poles are used, the majority taking the form of an inverted "V," while every fourth support is of a stronger nature, consisting of two inverted V's leaning against each other. The poles are square in form and mounted on concrete blocks. The spacing appears to be about 4 ft. 6 in. between wires, and the average height of the supports is 30 ft. I am

Mr. Watts. unable to give any details of the span, but it is fairly large. The most remarkable construction, however, is that of the 10,000-volt line. This is mounted on ordinary telegraph poles, and the insulators are fixed on iron supports screwed into the pole, a wire connecting the earth-wire with each of the iron screws. The line looks exactly like a telegraph line with extra large insulators, and it passes for a distance of 10 miles over houses, roads, and fields. The conductors are spaced about 2 ft. apart.

Mr. Welbourn. Mr. B. Welbourn (*in reply*): Mr. Isenthal's explanation of the function of the Moscicki condenser is opportune and goes, I think, to confirm the views that I expressed in connection with the protection of lines. I have had no experience with the Giles valve on an overhead line; but I know of a large distribution network of cables on which much trouble was experienced through pressure rises and where since Giles valves were installed two years ago the breakdowns have ceased. Mr. Isenthal's summary shows how difficult the question of protection may be. The inference is clear: there is great need for the invention of a combination arrester which will take care of all the different conditions that may be experienced.

Mr. McColl's contribution refers in the main to work at voltages which have not been employed in the United Kingdom. As stated in the paper, however, a raising of working pressures cannot long be delayed in this country, and then Mr. McColl's comparisons will prove very useful.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF THE 26TH FEBRUARY, 1914.

Proceedings of the 563rd Ordinary Meeting of the Institution of Electrical Engineers, held on Thursday, 26th February, 1914—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on Thursday, 12th February, 1914, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

Messrs. J. H. Johnson and O. L. Record were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Associate Members.

Browne, George Henry.
Harvey, George Miller.
Hogg, Patrick Mackintosh.

Graduates.

Church, Alfred David.
Day, Isaac.
Finlason, Walton Scott.
Levett, John Victor.
Millns, Percy Maurice.
Morris, Harold Arthur.
Parr, Walter Thomas.
Ravenscroft, John Dewhirst.

Students.

Balmford, Edgar.
Bhatt, Motiram Harikrishna.
Bolton, Charles Richard.
Boxall, Charles William.
Coombs, Charles Alfred.
de Hollanda, Raphael.
Easter, Charles Edward.
Gates, Reuben.
Ghose, Khagendra Nath.
Gillman, Ernest Percival.
Grose, Stewart Jewell.
Hall, Thomas Haffenden.
Hardie, Herbert John.
Haws, Norman.
Hopkins, Alfred Stephen.
Hornyold, Henry.
Jardine, Cecil William.
Knight, Cyril Sherwin.
McKenzie, Hector James.
Morton, Charles Albert.
Painton, Edgar Theodore.
Palmer, William Samuel H.
Richardson, Walter.
Tindall, Frederick Joseph, B.Eng.
Tolley, Henry John.
Wells, Reginald Iredale.
Woodside, Hugh.
Young, Clifford Neil.

TRANSFERS.

Associate Member to Member.

Butters, John Henry.
Sykes, James Arthur.

Graduate to Associate Member.

Golden, William Thomas.
Maytham, Albert Archibald.

Student to Associate Member.

Brown, Ivan Crisp.
Brown, William.
Dixon, Victor Cyril.
Harley, Thomas Edgar.

Student to Graduate.

Ayengar, T. K. Ramasami.
Brander, James.
Cheal, Arthur Ernest Edward.
Christian, David Adam.
Curling, Harold William.

Donations to the *Building Fund* were announced as having been received from The Association of Municipal Electrical Engineers of Greater London, R. A. Dawbarn, Professor A. Hay, D.Sc., J. S. Highfield, H. Hirst, Vice-Admiral Sir H. B. Jackson, K.C.B., F.R.S., Professor J. T. Morris, D.Sc., H. M. Sayers, A. Stroh, Sir Joseph Swan, D.Sc., F.R.S., A. Wright, and L. T. Young ; and to the *Benevolent Fund* from H. Alabaster, G. F. Allom, A. B. Anderson, I. Braby, R. A. Chattock, V. K. Cornish, B. Davies, A. Denny, J. Devonshire, H. C. Donovan, B. M. Drake, W. Duddell, F.R.S., K. Edgcumbe, F. Gill, Dr. R. T. Glazebrook, C.B., F.R.S., B. B. Granger, F. E. Gripper, C. C. Hawkins, K. Hedges, D. Henriques, S. Hill, H. W. Kolle, A. E. Levin, J. R. P. Lunn, L. B. Miller, W. M. Mordey, E. Parry, The Hon. Sir C. A. Parsons, K.C.B., F.R.S., W. H. Patchell, A. H. Preece, W. L. Preece, W. R. Rawlings, T. Rich, R. Robertson, S. R. Roget, A. Siemens, A. Stroh, A. J. Stubbs, A. P. Trotter, T. C. T. Walrond, and C. H. Wordingham, to whom the thanks of the meeting were duly accorded.

A paper by Mr. F. Lydall, Member, entitled " Motor and Control Equipments for Electric Locomotives " (see page 384), was read and discussed, and the meeting adjourned at 10 p.m.

INSTITUTION ANNOUNCEMENTS.

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* *Bound with* "In the Court of the Railway etc. Commission," pt. 6.

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THE JOURNAL OF
The Institution of Electrical Engineers

Vol. 52. | 1 APRIL, 1914. | No. 231.

THE DESIGN OF ROLLING STOCK FOR ELECTRIC RAILWAYS.

By H. E. O'Brien, Associate Member.

(Paper first received 2nd February, and in final form 21st February, 1914; *read before* The Institution *12th March,* 1914.)

It is now a well-known fact that the possibility of the application of electric traction proving remunerative depends on the density of the traffic plus the possibilities of development; in other words, the larger the number of stations per mile the greater is the probability that electric working will result in a reasonable return being obtained on the capital expended. It must also be remembered that on railway systems embracing several large towns the suburban and interurban passenger mileage is a very large percentage of the total passenger-train mileage. In the more densely populated parts of England the train mileage on lines of railway companies which have sufficiently heavy suburban traffic to make electrification worth considering is probably not less than 20 per cent of the total passenger-train mileage. Railways engaging in electrification of large suburban areas therefore find that the cost of operation of the electrical services is an important proportion of their total expenditure; and bearing in mind the large addition to their original capital expenditure involved by electrification, every means of reducing both the capital cost and the cost of operation becomes a matter of serious importance and worth the minutest investigation. The whole cost of electrification and of subsequent operation will depend on three factors :—

(1) the number of stops per mile;
(2) the schedule speed of the trains;
(3) the weight of the trains.

Factor (1) is fixed by the nature of the district.

Factor (2) is a matter for determination by the management: the needs of the population of one district can only be served by a very fast service, while in another district a slower schedule with more frequent trains will attract just as much traffic. The main object of electrification is of course increased traffic, and this is obtained by enabling people to live at a distance from their work and yet reach it without spending an unreasonable amount of time in travelling; and also to induce their dependents to travel as far and as often as possible. The office hours, and the meal-times customary in this country fix within narrow bounds the limits of an electric system. The maximum length of time that a business man will consent to spend in a train at each end of the day is 45 minutes, and this is also the maximum period that will allow other persons an hour's shopping between one meal and the next. This time limit represents a radius of 22 miles at a schedule speed of 30 miles per hour. With stops one mile apart such a schedule is practically the highest attainable with any type of train or motor.

If the train equipments had to be designed for lines with stations placed at uniform distances apart, and on a level track, the problem of securing the most economical motor and control would be comparatively simple. But it will often happen that a profitable electrification will involve runs with very short distances between the stops in the vicinity of a large town, and also runs with much longer distances between the stops as the trains get farther from the urban area; and very possibly at the extremity of the electrification a secondary urban area is approached necessitating a number of stops in close proximity to each other.

The most remunerative traffic will be that between the extremities of the electrification, between the primary and secondary urban areas; consequently the equipments will have to be designed so as to make a journey of this length a reasonable one. The gradients also vary, and a long run, say two miles, may be on a continuous up-grade of 2 per cent, or even less, while the short runs may be on comparatively level ground. Expresses as well as stopping trains will be required (as has been found on the London Underground Railways), and as in most cases the setting aside of special stock for express services would involve extra capital expenditure, a compromise has to be accepted both in the motor characteristic and in the gear ratio. The equipments would normally be of such a character as to permit of a fairly large percentage of coasting on the longer runs for maximum economy, but the commercial management will soon realize that time can be saved by maintaining full speed nearly as far as the stopping-points in these cases; also as the district develops extra stations will be introduced, which will make the original gear ratios in-

correct. In consequence the equipments will normally run in such a way as to require a high energy consumption. This energy consumption is the sum of that wasted in the resistances and motors, of that wasted in the brakes, and of that utilized in overcoming train resistance. The first two of these losses are directly proportional to the weight, and the third—the train resistance—is so nearly proportional to the train weight that it may be taken as being so for practical purposes. Fig. 1 shows the resistance of the Lancashire & Yorkshire Railway Company's trains as actually obtained by the coasting method.

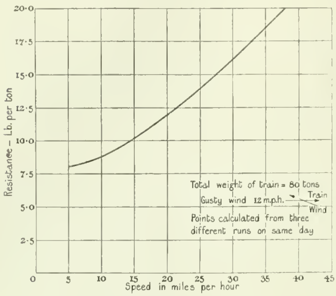


FIG. 1.—Resistance of 2-Car Train.

Fig. 2 shows the approximate division of the total energy between its various components.

The curve in Fig. 3 shows the percentage of the whole used for acceleration for runs of half a mile and upwards. The schedule speed is maintained constant by prolonging the coasting period for the longer runs. This curve emphasizes the enormous importance of light rolling

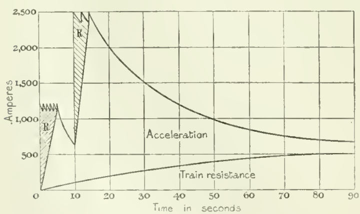


FIG. 2.—Typical Curves showing Energy Losses.

stock, as far as the influence on the energy consumption of the trains on high-schedule short-distance suburban services is concerned. It will be seen that the energy consumed varies almost directly as the weight of the trains, although for runs between stations less than one mile apart the importance of the acceleration component increases as the distance decreases.

High energy consumptions per ton are likely to accompany commercially successful electrifications, and the sole variable factor that can be attacked, and which enormously influences the whole problem, is the weight of the rolling stock. It is therefore very important to consider in detail how rolling stock may be built so as to give a maximum value to the ratio—number of seats provided per ton weight of train.

The fact that the coaches must be comfortable must not be lost sight of; but there is no need to assume that light coaches are uncomfortable to ride in. Excellence in riding is obtained by the use of bogies of the maximum wheel base permissible, and by careful design of the seating and springing systems; also by concentration of the motor masses as near the bogie centre and as high as possible. The necessary protection against the possible effects of collision and fire must be provided, but such protection is not necessarily obtained by extra weight.

The lighter the colliding bodies the less the force of the collision, and in the case of collisions with bodies of infinitely large mass, such as with a dead end, the lighter the train the less severe are the effects. The bodies of an electric train form a homogeneous whole; there is practically no sandwiching of heavy and light bodies such as

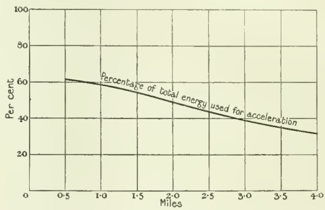


FIG. 3.—Curve showing Percentage of Energy Input used for Acceleration for Runs of ½ mile and upwards.

must occasionally occur in steam trains: the weight of the heavier coaches is mainly in the bogies.

The disastrous effects of collisions are mainly due to the frame of one coach over-riding the frame of another and the bogies being packed together under the coaches.

It is not a difficult matter so to design the ends of the underframe as to prevent over-riding of one underframe upon another, and in the United States it is proposed that the bogies should be anchored more securely to the bodies in order to throw more of the energy lost by the collision into the bogies and to use them as stops to prevent over-riding. It is much more rational to proceed on these lines than in increasing the strength of the underframe, pillars, and roof.

Non-inflammability has hitherto been secured by the extensive use of steel instead of wood, but there is no reason why a lighter metal should not be used.

Lightness of construction may be obtained either by using reduced scantlings, which is undesirable as involving a reduction in the factor of safety, or by using lighter materials, or by using materials of greater intrinsic strength, thus enabling the scantlings to be reduced without sacrificing the strength of the whole structure. Unfortunately it is necessary to buy more costly materials in order to

combine strength with lightness; some of the lightest and strongest materials are still very costly, one proprietary article exceedingly suitable for rolling stock construction costing over £300 per ton. It is necessary at this point to consider to what extent increased capital expenditure is justified by the saving effected in running expenses.

Assuming 100 watt-hours per ton-mile at the ends of the high-tension feeders as a typical energy consumption in the near future, and 60,000 miles per annum as a probable mileage per car per annum, then every ton of motor car involves a consumption of 6,000 kilowatt-hours per annum. This is equivalent to an annual expenditure of £12·5 per annum per ton for energy if a total cost of 0·5d per unit is assumed. It is recognized that with centralized power distribution a lower selling cost than this is attainable, but except on the North-East Coast it is hardly probable that electricity could either be bought from companies or corporations or produced by railway companies themselves at a cheaper rate. Unfortunately the evening railway peak coincides with the winter tramway and lighting peak in large towns, thus militating against a reasonably cheap supply. Production by a railway company has the advantage that no selling or advertising charges, or charges involved in laying mains in streets, have to be borne. Further, the operation of a generating station and sub-stations falls naturally within the province of the Chief Mechanical Engineer's Department, and not only is the highest efficiency obtained but also management charges are reduced to a minimum, and the changes of policy that occur with municipal stations are avoided.

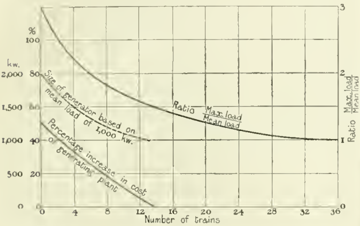


FIG. 4.—Influence of Number of Trains upon Capital Cost.

The cost of repairs to each ton of rolling stock will amount to about £5 per annum for a high-speed service; and its passage over the rails will probably involve repairs to the track equivalent to another £1 per annum, or a total cost per ton of motor car of £18·5 per annum. On similar lines the cost per ton of trailer car will be about £14·5 per annum, the energy charge remaining constant and the other charges being smaller. The capital cost per ton of motor car will be approximately £70, and per ton of trailer £45. Hence every ton of weight saved represents (taking interest and depreciation on capital at 10 per cent) a total saving per annum of £25·5 per ton of motor car and £19 per trailer car per ton per annum. It becomes therefore a commercial proposition to spend as much as £185 per motor and £145 per trailer in labour and material in order to save a ton in weight on the particular service chosen for this illustration, or, in other words, every pound of weight saved produces an economy of about 2d. per annum, or is equivalent to securing one additional passenger per annum in perpetuity.

But further considerations of capital expenditure are involved. Every ton of coach involves a consumption of 6,000 kilowatt-hours per annum, and plant has to be provided to produce this energy. It will be observed in Fig. 4 that the maximum demand for energy acceleration is exactly proportional to the weight of the train. The capital expenditure in small or medium systems does not decrease directly as the weight of the train, but is affected by the ratio of the maximum load to the mean load. After a certain point the capital expenditure per ton of train will decrease owing to the reduced cost per kilowatt of the power house and sub-stations, but not sufficiently to affect in any marked way the arguments advanced in this paper.

In a plant supplying an infinite number of trains the maximum and mean loads would be the same, and in a plant supplying only one train the ratio would be approximately three to one. An average plant carries about 50 per cent overload momentarily, and consequently the cost of the turbines, generators, rotary converters, and transformers will be more than increased proportionately to the weight in any system carrying less than about 14 trains, as shown in Fig. 4. Hence the smaller the system and the severer the schedule the more important is the weight of the train.

In designing cars to give a maximum seating capacity for a minimum weight a careful investigation of the maximum possible width is the first essential, because extra seats can be given by extra width with a smaller increase in weight rather than by extra length: in many cases extensive slewing of tracks will be justifiable if practicable where structural alterations to the platform are not too expensive, or where tunnels do not prohibit this. In settling the dimensions of the cars the ultimate range of the rolling stock must be considered, but it does not appear necessary or desirable to make suburban stock of such dimensions that it will conform to the minimum loading gauge for the whole of the system. If bows are required on the roof to collect current from an overhead wire, an elaborate survey of the whole system that may ultimately be served by overhead conductors will be essential, as places occur on English railways where it is absolutely impossible to run an overhead conductor.

If 60-ft. coaches are used an extra 12 in. in width will give 15 more seats on a basis of 4 sq. ft. per passenger; the width of the gangway must be 2 ft., and consequently if the cars can be made 10 ft. wide, instead of 9 ft., five seats can be given crosswise instead of four. If the average coach seats 100, ten more seats per car will result in a 10 per cent decreased capital expenditure on rolling stock. The increase in weight will be limited to that for the increased width of the floor, roof, and seats, and is about $2\frac{1}{2}$ cwt. per 10 ft., or 15 cwt. per 60-ft. car; or in other words, the additional seats gained by the extra width represent 1 cwt. per seat. If this extra seating is provided by extra coaches an extra weight of about 5 cwt. per seat is involved.

The length of the coach must next be considered; this will be determined by the throw of the coach, the versed sine of the worst curves on which trains will pass each along a train in search of a seat or of friends is much appreciated. The absence of doors decreases the cost of maintenance, and appreciably increases the strength of the

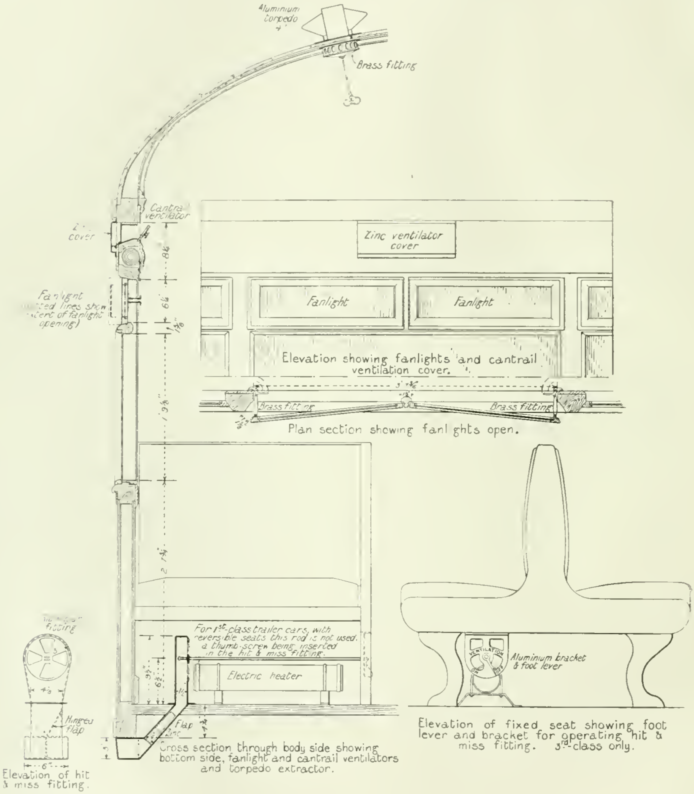


FIG. 5.—Arrangement of Ventilation on New Electric Trailer Cars on Lancashire & Yorkshire Railway.

other, and the minimum width between the tracks at that point. With corridor coaches, or side-door coaches with doors opening inwards, or sliding doors, a very small clearance can be adopted with safety.

The comfort of the corridor coaches is greater than that of the side-door coach, and the possibility of moving body, while ventilation and heating can be carried out more uniformly and efficiently.

The ventilation of the cars has considerable influence on the energy consumption of the coaches, because the heating load becomes very appreciable in cold weather. On inter-urban railways in the English climate it may be estimated

that there will be at least an increase of 9 per cent in the load in the winter months due to heating only. It is most important to secure a minimum weight for the heating equipment, and it would pay so to arrange it that it could be entirely removed when not required.

The latest arrangement of ventilators and heaters as used on the Lancashire & Yorkshire Railway is shown in Fig. 5. It will be noticed that cold air is collected along the sides of the coach at the floor level and is passed over the electric heaters as it enters the coach, a supply of warm fresh air being thus secured, which is eventually extracted by either the ventilating fan or the ordinary torpedoes. It is essential that the heaters should be raised well above the floor level so that the floor can be washed thoroughly from end to end without danger of damaging the electrical apparatus. Drain holes should be provided in the floor for the water used for washing to run out, and all corners should be provided with a curved moulding of either wood or sheet aluminium so that the corners can be thoroughly brushed.

Ventilation can be equally well effected on the elliptical type of roof by means of fans communicating with shallow ducts running the full length of the roof. The weight of a fan-extracting equipment is practically the same as that of a set of torpedo extractors, so that the net increase due to the use of fans will be the weight of the shallow troughing which runs the length of the car.

The fanlight and cantrail ventilators are more for summer than for winter use. The result of adopting the corridor coach with such a system of ventilation and heating is a uniformly warm and comfortable coach—a result which cannot possibly be obtained with side doors.

The absence of doors which may fly open and foul trains on an adjacent track enables the maximum width of coach to be used, with a consequent increase of earning capacity, and also does away with the possible danger of trains leaving a platform with the doors adjacent to the seats in an open position.

As previously stated, the limit of suburban services is about 22 miles, and coaches that have to traverse such a distance in the open country must be of the corridor type in order to give the great comfort which is necessary to develop the traffic to its greatest extent.

Having decided on the maximum length and width permissible for the body, it is important to consider further the directions in which weight can be saved in this part of the coach, as this has a very direct influence on the total weight. A light body with weights distributed to the best advantage permits the use of a lighter underframe, and this in its turn reduces the rated horse-power of the motors for a given schedule.

The reduction in the rated horse-power of the motors permits of lighter bogie scantlings, and also in many cases of a lighter design of control apparatus. The influence of the weight of the body is therefore progressive throughout the whole car, and for every ton of weight saved in the body it is probable that another ton can be saved in the bogies and motors.

The roof of the body may be either of the clerestory or elliptical type. The clerestory type of roof is very little used in this country on modern rolling stock, but is still extensively used abroad, mainly on account of its supposed superiority for ventilation purposes. The elliptical roof is lighter than the clerestory type, and also enables a coach to be more uniformly lighted, owing to the superior reflecting qualities of the smooth surface of the elliptical roof. In order to obtain the best illuminating effect the finish of the roof should be a matt-white and the lamps shaded so that the filaments do not come into the line of sight. The design of the clerestory roof is inherently weak, and is specially unsuitable where bows have to be supported on the roof. It is to be noted that the presence of bows which will weigh 10 cwt. necessitates a considerably stronger roof, not only to carry the weight of the bow, but also because it will be frequently necessary to walk on the roof, when attending to inspection and repairs.

Very little difference is made in the weight by the use of any material other than wood for the roof sticks and pillars. It would appear that there is little object in using steel for the pillars, as some of the Australian hard woods are practically as non-inflammable as metal, when the scantlings used are not too small.

For the actual outside roof, wood, steel, or aluminium can be used. There is practically no difference between the weight of the roofing in a wood or aluminium roof, but approximately half a ton in weight can be saved on a 60-ft. car by the use of an aluminium roof instead of a steel roof.

At this point it may be as well to point out that aluminium, in addition to its extremely light weight, has the advantage of being non-corrodible, and therefore requires very much less painting than either steel or wood. A considerable saving should also be effected when repainting is required, as a single coat of paint and one of varnish ought to meet all requirements.

The main difficulty that has been encountered by the use of aluminium is the erosion of the holes where screws or nails are put through the plates to secure them. If the coach, however, is properly constructed and the movement of the structure is not too great, this is not of much consequence, as shown by the sample aluminium panel exhibited.

By the use of aluminium for the outside panels a saving of nearly half a ton can again be effected as compared with steel.

The comparative weights and cost of various panelling materials are as follows :—

		£	s.	d.
426 sq. ft. steel panelling 18 W.G. at 1·95 lb. per sq. ft.	830·7 lb.	3	9	9
426 sq. ft. baywood panelling 3/8 in. thick at 1 lb. per sq. ft.	426 lb.	10	6	4
426 sq. ft. aluminium panelling 16 W.G. at 0·88 lb. per sq. ft. ...	375 lb.	18	4	2
426 sq. ft. 4-ply panelling 5/16 in. thick at 1·06 lb. per sq. ft.	452 lb.	16	17	6

The weight of the glass in a modern coach is a very considerable item, amounting to 7 cwt., or 1·4 per cent of the weight of the whole coach. Though it is a comparatively small matter, some slight weight is saved by having a perfectly plain finish to the interior of the car. Not only does this produce the most artistic effect, but it also facilitates inside cleaning and avoids the use of expensive woods, carved work, and meaningless pieces of scroll work and pillars.

It is also possible to effect economies in the seats. If throw-over seats are used it is essential to use iron castings, as aluminium is not strong enough to stand the constant turning-over of the seats. By the use of fixed seats, instead of turn-over seats, the same material being used in each case, approximately 10 lb. per seat can be saved. By the use of aluminium or other light alloy castings for the fixed seats, the weight would probably be reduced to half that of reversible seats, and, as the seats per car weigh approximately 1·5 tons, nearly 0·75 ton saving in weight can be effected in this direction.

If traffic considerations permit, fixed seats may be used, with a consequent increase in the seating capacity of approximately 10 per cent per car, which is, of course, equivalent to an eventual reduction of 10 per cent in the total weight of the rolling stock to be moved.

It is becoming generally recognized that on the comparatively short journeys made by suburban rolling stock the public do not mind which way they sit; consequently fixed seats should always be used. Weight can be economized by not providing seats, or by leaving a large amount of standing space. This is not advisable, and as far as possible seats should be provided for every passenger.

Fig. 6 shows in diagrammatic form how fixed seats provide the increased seating accommodation. It is advisable to provide a certain amount of open space in the vicinity of the gangways, as this forms a sort of a reservoir for passengers to stand in when they are getting in and out simultaneously, or when a large number of people are getting out at the same time.

Wood has very commonly been used in the construction of the floor. The relative weights of floors of various materials are as follows:—

	Ton	cwt.	qr.	lb.
Weight of floor, yellow pine 1 1/2 in. thick	0	16	0	19
Weight of steel plate (5 lb. per sq. ft.) with yellow pine covering 3/4 in. thick ...	1	13	1	1
Weight of corrugated iron, No. 18 gauge with expanded metal 3/4 in. mesh and 1 in. thick composition at 7 lb. per sq. ft.	2	10	0	4
Weight of composition 1/2 in. thick and yellow pine 1 1/2 in. thick	1	13	3	5

It would seem probable that the floor of the future would consist of corrugated aluminium plates filled in with some form of composition, such as treated cork, to a sufficient depth to cover the crests of the corrugations by about 1/4 in.

The design of the underframe depends largely upon the weight of the body and upon the size of the motors and the motor bogies. It is very important that the motors should not be so large as to come up within the framing of the motor-car, as it then becomes very difficult to introduce the necessary diagonal bracing in the vicinity of the bogie centre. If this diagonal bracing is to be omitted the sole bars have to be made of a correspondingly thicker section, thus increasing the weight. Up to now the use of a high-tensile steel has not been sufficiently considered in the construction of underframes; such steels have been extensively used in motor-car construction and in bridge building. So far as the author is aware they have not been applied to electric rolling stock. The usual structural steel is that which complies with the British Standard Specification No. 17A, having a breaking strength of 28 to 32 tons per sq. in., with an elongation of not less than 20 per cent.

The relative strengths of this steel and two alloy steels used at present, in motor-car construction, but equally available for electric rolling stock, are as follows:—

Steel	Max. Stress. Tons per sq. in.	Elastic Limit. Tons per sq. in.	Elongation on 2 in. Per cent	Reduction of Area, Per cent
Nickel* 3%, C 0·2%	30	19	31	31
Vanadium 0·27%, C 0·2%	44	33	19	41
British Standard Specification for carriage underframe	30	14	20	50

These steels are nearly twice as strong as a steel usually employed to-day, and in consequence the scantlings can

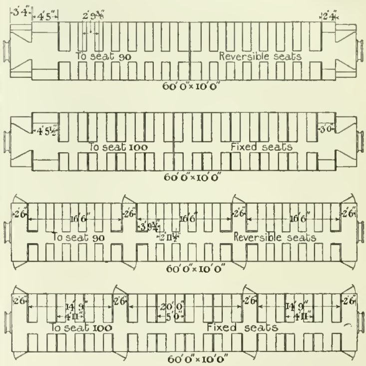


FIG. 6.

be reduced by at least 25 per cent in area, with a corresponding reduction in weight.

The weight of an underframe for a 60-ft. trailer coach is approximately 5 tons. Nearly a ton of this weight might be saved by the use of suitable material. It is recognized that alloy steels are more expensive and are slightly more difficult to roll, but there should not be more than 100 per cent increase in cost per ton of material, while the labour involved in erection would of course be less.

As the first cost of underframe material is low and will never exceed more than £7 10s. per ton, any saving in weight made by the use of more expensive material will easily pay for itself.

The disposition of the weights of the apparatus attached

* Rolled plate.

to the underframe has a considerable effect on its design; and it will be seen from Fig. 7 that the weight per foot-run, and the brake, resistances, and control apparatus of the motor cars should be distributed as far as possible along the length of the body, even if it involves some slight increase in the cost of cabling.

The stresses on the underframe will be relieved if the vacuum pump and motor, or in the case of the Westinghouse brake the air compressor and motor, are made as light as possible. Considerable progress has been made with the design of high-speed compressors for a Westinghouse brake, but a vacuum brake is so much simpler and so much cheaper to maintain that there is a considerable cars and trailer-cars, and it will be noticed how much more severely the body is stressed, and how important it is to keep the weights as low and as near the centres of the bogies as possible.

The bogies generally may be divided into two broad classes, those arranged with equalizing beams between the axles, and those built on the lines of the ordinary English carriage bogie. The equalizing type of bogie is always the heaviest type, and is quite unsuitable for English railways with their excellent permanent way. It may, however, be desirable on American interurban roads with poor road beds.

The ordinary type of bogie used for carriages on the

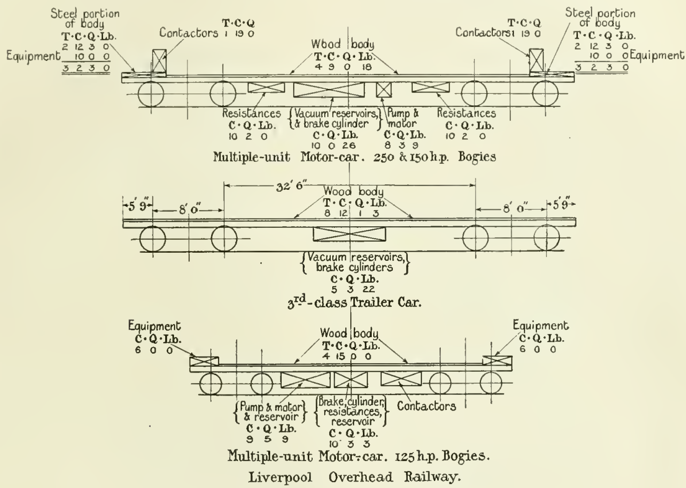


FIG. 7.—Distribution of Weights on Underframe.

field for a high-speed vacuum pump of light weight. A pump somewhat on the lines of a motor-car engine but with automatically actuated valves will probably be used in future for this purpose. The reservoirs which are essential to the vacuum brake should be made of aluminium.

In order further to reduce the weight of the body, the use of aluminium cable should be considered, though the difficulty in jointing introduces a serious fire risk, and in many cases renders its use inadvisable; and in connection with the contactors, wherever it is possible to use bar connections aluminium bar should be used rather than copper, and wherever castings are subjected to light stresses aluminium castings should be used.

Fig. 7 shows the approximate distribution of the weights, and the bending moments caused by them, for both motor-steam railways of this country may be built with elliptical or spiral bolster springs, either outside or inside the wheels. There is a considerable advantage in putting the springs inside the frames, as this enables the bolster to be made wider and the bolster spring to be put farther away from the centre-pin of the bogie, thus tending to diminish rolling. There is a considerable saving by using spiral bolster springs instead of elliptical bolster springs; nearly 0·75 ton per coach can be saved in this way.

In the author's experience elliptical bolster springs are quite unnecessary for the purpose of steady riding. The best results are obtained by having short, stiff semi-elliptical springs over the axle-boxes with assistant helical springs at their ends.

The wide frame involves an increase in weight; but on

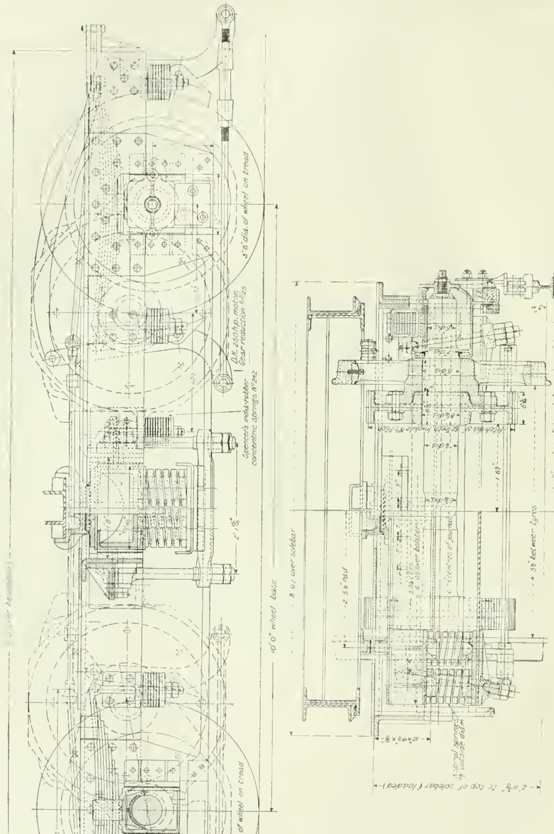


FIG. 8.—Motor Bogie—10-ft. Wheel-base.

TABLE I.

Motor Cars.

	1		2	3	4	5	6	7		8	9		10	11	12		13	14
Number of motors per car	4	4	2	4	4	4	2	2	2	4	2	2	2	2	2	2	2	4
Rated horse-power	150	250	125	150	200	100	100	150	150	175	210	150	125	200	125/140	200/225	200	250
Temperature base for rated horse-power, deg. Fahr.	75	75	135	117	135	—	—		—	135	135	135	108	135	135	135	—	135
Gear ratio	1·95	2·48	3·94	3·5	3·5	2·8	2·79	3·24	3·24	4·23	2·93	3·68	1·61	1·88	3·8	3·15	2·3	—
Diameter of wheel (in.)	42	44	35	38	38	33	36	36	36	43½	43½	43½	37¼	36	34¼	34¼	36	—
Revs. per min. 30 miles an hour	470	568	1,140	927	927	853	778	904	904	977	676	850	436	524	1,120	970	640	—
Weight of motor with gear (lb.)	6,350	9,240	4,370	5,150	6,100	3,960	4,387	3,940	3,940*	6,384	6,496	5,768	4,350	6,100	4,685	6,470	6,000	7,933
Motor, lb. weight per rated horse-power	42·3	36·96	35	34	35	39·6	43·8	26·26	26·26	36·5	30·93	38·45	34·8	30·5	35·3	29·3	30	—
Bogie wheel-base (ft.)	8 0	10 0	6 0	7 0	7 0	6 0	7 0	7 0	7 0	8 0	8 6	8 6	7 0	7 0	6 0	6 8	7 0	—
Weight of motor car (tons)	51·5	67	23	40·3	44	35·75	20	30	29·75	51·5	40	38	39·55	47·22	25·15	34·75	47·5	—
Weight of motor bogie complete with motors and brake gear (tons)	12·5	17·85	7·7	9·80	12	9·5	5	9·7	9·7	13·8	12·8	12·1	9·45	12·27	8·84	11·87	12·5	7·14
Weight of bogie without motors (tons)	6·5	8·85	3·7	5·3	6·56	5·97	3·05	6·2	6·2	8·1	7	6·95	5·57	6·3	4·66	6·1	7·15	—
Weight of car body complete with all electric and brake equipment ready to drop on bogie... (tons)	25·45	31·7	13·3	20·70	20	17·75	9·85	16·67	16·42	23·91	22·7	21·4	20·62	29·77	12·47	18·25	29†	24·33
Weight of electric equipment, including motors, cables, and control gear for motors and resistances, but not pump for brake, per car (tons)	14·33	23·67	5	14	18	9·30	one motor 2·57	5·6	5·6	18·85	14·45	11·55	9·65	8·5	7·31	11·62	—	5
Length of car	ft. in. 63 0	ft. in. 63 7	ft. in. 45 6	ft. in. 51 10	ft. in 51 10	ft. in 60 0	ft. in. 45 0	ft. in. 56 6	ft. in. 56 6	ft. in. 57 8	ft. in. 60 0	ft. in. 60 0	ft. in. 53 10	ft. in. 62 0	ft. in. 47 0½	ft. in. 51 0¼	ft. in. 64 5¾	ft. in. 65 3
Width of car	9 10¼	9 10¼	7 10	8 9	8 9	8 7	9 3	9 0	9 0	8 0	9 0	9 0	8 6	9 8⅝	8 9½	8 10	9 11½	10 4½
Length of passenger compartment	42 6½	36 3[illegible]	30 0	34 9	34 9	41 9	40 0	34 11½	45 1	—	52 0	52 0	44 3	48 11½	39 0	39 0	53 7⅝	
Centre to centre of bogie	40 6	45 0	29 0	35 0	35 0	44 0	32 0	40 0	40 0	37 0	42 0	42 0	34 3	38 6	33 2	36 0	39 0	—
Floor area (total) in square feet	523·58	581·65	356	410	400	435	382	480·25	480·25	400	486	486	450	510	400	437	487·75	—
Floor area for passengers in square feet	387	337·12	227	322	312	320	282	297	382·5	370	425	425	376	410	350	384	472·17	
Percentage $\frac{\text{passenger area}}{\text{total area}}$	73·8	57·9	64·5	79	78	74	95	61·75	79·5	92·5	87·45	87·45	83·5	80·4	87·5	88	96·[illegible]	—
Square feet per ton for passengers	7·6	5·03	10	11	7·5	8·7	16·6	9·9	12·85	14·7	10·63	11·18	8·5	7·75	12·45	9·85	—	—
Square feet per ton (total)	10·3	8·69	15·5	14	10	11·8	17·7	16	16·2	15·9	12·15	12·79	10·2	9·64	14·3	[illegible]	—	—
Kilowatts for brake	3·3	3·3	—	—	6·0	—	—	3·0	3·0	6·6	—	—	7·0	4·74	4·15	—		—
Kilowatts for heaters	4·8	4·8		—	3·5	—	—	4·8	4·8	—	—		8·4	18·0	5·7	—	[illegible]	—
Kilowatts for lighting	2·04	2·04		—	1·60		—	0·96	0·96	0·86	—	—	2·24	0·59	1·58	—	[illegible]	—
Total kilowatts for auxiliaries	10·14	10·14		—	11·10	—	—	8·76	8·76	7·46	—	—	17·28	23·33	11·73	—	26·88	
Square feet of floor area per candle-power	0·64	0·56	—	—	0·78	—	—	0·77	0·99	0·72	—	—	0·75	0·71	0·36	—	1·12	—

* Without gear. † With bogie.

account of the steadier riding obtained by the wider centres of the bolster springs it is worth having.

Cast iron is very usually used for axle-boxes, but cast-steel axle-boxes and cast-steel axle-box slides will enable the weight of these parts to be reduced by 22 per cent.

In connection with the weight it is very important to consider the arrangement of brake-blocks. It is very usual in modern designs to arrange for blocks to press on either side of the wheels with a view to eliminating the stresses due to a one-sided application of the brake. The double brake-block arrangement involves, however, a very considerable increase in weight, amounting to nearly one ton per coach. The increased stresses, however, will mean increased diameter of the axles, increased bosses on the wheels, and an increase in the size of the motor housings, which will amount to a greater weight than that saved by the single brake-block arrangement.

Fig. 8 shows the latest motor bogie as adopted by the Lancashire & Yorkshire Railway.

The scope of this paper does not permit a full discussion of the weights of the motors, controllers, and resistances, but it should be pointed out that the totally enclosed railway motor has not been found really necessary in this country. The motors operated by the Lancashire & Yorkshire Railway Company are run continuously with as many ventilating openings as possible, and no trouble has been experienced except on one occasion when very fine snow was being blown horizontally in large quantities, and even in this case the trouble arose more with the resistances than with the motors. In order to get a light motor it should be of the self-ventilating type, and the movement of the armature should produce a powerful draught through the motor.

Better results can be obtained with independent blower sets, but the complication of having an additional small motor to maintain, and the necessary air ducts do not compensate for the saving effected. Generally speaking, a light motor means a high-speed motor, and a high-speed means a large gear ratio; but it will be found cheaper to renew gears than to carry a standing charge of moving an unnecessary weight.

The tables accompanying this paper give particulars of the motor and trailer coaches used by the leading electric railway companies in England and the United States, and it will be realized that the question of weight has not had the same attention given to it as the question of equipment.

Many of the electric railways which were pioneers in this country and in America will in a few years be reaching the period when, in the natural course of affairs, the gradual renewal of their rolling stock will have to be undertaken, and it is to be hoped that the general considerations outlined in this paper will assist in directing the attention of electric railway engineers to increasing the capacities of their systems and decreasing their maintenance by the provision of lighter rolling stock.

The principles outlined in the paper are equally applicable to electric tramway systems, light railways, and high-speed suburban services operated by steam engines. Owing to the greater "train resistance" of trams the energy consumption in this respect is not exactly proportional to the weight; but on account of the great frequency of stopping and starting, the acceleration component completely overwhelms the other aspect of the case and lightness of construction becomes a matter of the first importance if economical working is to be attained.

TABLE II.

Trailer Cars.

	1	2	6	7	8
Diameter of wheel ... (in.)	42	29	30	—	33
Bogie wheel-base ...	10 ft. 0 in.	5 ft. 0 in.	5 ft. 6 in.	—	—
Weight of bogie ... (tons)	5·06	2	3·5	4·5	3
Weight of body ... (tons)	14·85	9·5	12·75	13·25	—
Length of car ...	63 ft. 7 in.	—	59 ft. 6 in.	43 ft. 0 in.	32 ft. 0 in.
Length of passenger compartment ...	55 „ 4½ „	39 ft. 0 in.	49 „ 9 „	35 „ 0 „	—
Centre to centre of bogies ...	45 „ 0 „	29 „ 6 „	—	28 „ 6 „	20 ft. 0 in.
Floor area (total) in square feet ...	565·9	—	427·5	347	256
Floor area for passengers in square feet ...	514·29	305	381·5	286	256
Percentage $\frac{\text{passenger area}}{\text{total area}}$ ...	90·8	85·8	89	82·42	—
Square feet per ton for passengers ...	20·9	23·5	19·3	15·89	—
Square feet per ton ... (total)	23·0	27·4	21·6	19·28	—
Kilowatts for heaters ...	4·8	—	—	4·8	—
Kilowatts for lighting ...	1·5	—	—	0·76	0·80

Discussion before The Institution, 12th March, 1914.

Mr. W. Casson: I think there can be no doubt as to the importance of the question of weight which the author has put before us to-night, and the much more direct effect that it has on the operating costs of electric railways than on those of steam railways. I cannot help thinking, however, that he has gone rather far in estimating the probable effects of small reductions in weight on the maintenance costs, when one considers the rough and ready conditions that obtain in operating. There is one question that I should like to ask. Should not the horizontal scale in Fig. 2 be "time in seconds" and not "speed"? So far as Fig. 3 is concerned, I am not quite sure whether the percentage there is the percentage that the accelerating energy bears to the energy input of the train or to the energy output of the motor. If it be the former it seems to me to be about correct; but if it be the latter I think it is more like 80 per cent with stops half a mile apart. With regard to Fig. 4, I hardly think it would be found in practice that with such a small number of trains as 56 one would get anything like unity for the ratio of the maximum to the mean load. The number of trains on the underground system supplied from Lots-road power station is very much more than 56, and we should be only too pleased if we could get a figure of 1 for the ratio of the maximum to the mean load. Moreover, it is always necessary to provide against the contingency of an unusual number of trains starting at once. That is the kind of consideration that prevents these calculations being carried too far. If that were done we should be liable to have the whole arrangement upset by a slight change in the next month's time-tables. The same thing occurs to me in regard to the question of reckoning maintenance cost per ton of car. It seems to me that there are other considerations, which may be quite small and yet may have such an effect as completely to swamp the consideration of the weight in regard to maintenance, even if the weight is all put in the right place. For instance, the rolling stock on the Central London Railway is much lighter than that on the London Electric Railways; but from causes which I need not go into, its maintenance cost is considerably higher. The first electric rolling stock on the District Railway in which wood and aluminium were used is lighter than the more modern steel rolling stock, but it is more costly to maintain.

With regard to first cost, the original wood and aluminium stock was actually more expensive than the steel stock; it was cheaper, however, than our latest steel stock which is just being put into service, but it is difficult to make a correct comparison owing to the great general advance in the cost of material and labour for rolling stock.

The seating diagrams given by the author are of great interest, especially as showing the different views held by various people on what constitutes adequate seating room. People in the north country are supposed to be built on a larger scale than southerners, but I am quite sure that all our passengers would strongly object if they were placed in the seats that the author has provided on his trains. The seating room on the author's coach compares as follows with that on the District Railway:—

	Mr. O'Brien's Coach	District Railway
Longitudinal seats ...	just under 18 in.	20 in.
Cross seats	approximately 16 in.	$19\frac{1}{2}$ in.
Distance between centres of cross seats ...	4 ft. 11 in.	5 ft. 8 in.

I cannot help thinking that with the very large number of stops per mile on the District Railway there would be considerable difficulty in getting the passengers in and out of the cross-seat cars, especially with the comparatively small door openings that are provided. The other day I was told by a traffic superintendent of one of the railways that "railway engineers are much too fond of trying to crowd too many seats into the cars, whether they are comfortable or not. It would be better to have fewer seats, so that they can be made more comfortable." I certainly think that with the arrangement of seats and the small doors shown it would be difficult to handle passengers fast enough for stops half a mile apart. But so far as seating is concerned, as long as we provide the traffic department with floor area it is for them to say how they want to divide it. With regard to the question of vacuum brakes, the simplicity and the low maintenance costs must be admitted, but I do not know of any system operated with vacuum brakes that is running a service of the same sort that there is on the underground railways of London and New York. I do not say that such systems do not exist, but merely that I do not know of any. In any case I think there would be difficulties. I quite agree with the author as to clerestory roofs, and I fancy everybody does at present, but fashion seems to have a lot to do with this question. For rolling stock for use in the Tubes, however, where there is no room for outside ventilators, the elliptical roof introduces some interesting problems in ventilation. The author's remarks about bogie design and construction agree exactly with our experience on the underground railways, particularly as to its not being necessary to use elliptical springs on the bolsters. As a matter of fact one very satisfactory trailer bogie that we use has no elliptical springs at all; it has two helical springs over each axle-box, and helical bolster springs. I agree as to the weight of the equalized type of bogie and as to its being unnecessary for anything like that sort of service. As to its weight, the District Railway bogie, mentioned above, which has cast-steel side frames and a 7-ft. wheel-base, weighs less than an equalized bogie having a much more flimsy construction and only a 5-ft. wheel-base. The 7-ft. wheel-base bogie rides very much better and is far cheaper to maintain. With regard to the question of wheel-base, there is considerable difficulty in practice in reconciling the use of a long wheel-base with the placing of the motor masses near the centre of the bogie. That is one of the difficulties experienced by designers in reconciling the requirements for a satisfactory bogie. The outside frames shown in the author's design are interesting, and where the positive conductor rail is far enough away to give room for the bolster swing links in that position it must be a great advantage. Unfortunately we have not got that. With regard to the question of motor bogies in general, I cannot help thinking that

Mr. Casson. engineers do not take into account to anything like a sufficient extent that they are giving that bogie the work of a locomotive to do; in fact, as far as tractive effort is concerned, it does more work than a good many locomotives. I do not think the motor bogie receives anything like the attention that it ought to do. If we took a lesson from the locomotive engineer and went more on the lines of a locomotive in building motor bogie-frames it would be much better. With regard to the question of cast-steel axle-boxes, I agree with the author, but we do not find cast-steel axle-box slides are very good. They save an almost infinitesimal amount in weight and they wear themselves and the axle-boxes out very rapidly. We prefer cast iron. With regard to the table on page 453, I cannot help thinking it would have added very much to its interest and the amount of information that we get from it if instead of taking the motor car as the unit for comparing weights, we had what I may call the traffic unit, that is to say, the motor car and the trailer car or cars, $1\frac{1}{2}$ or $1\frac{1}{4}$, or however many trailer cars go with each motor car. For instance, I recognize No. 2 in Table I as the Central London Railway Standard motor car. We have reduced the number of cars per train now since the motor omnibuses became so aggressive, but when these motor cars were originally introduced there were two motor cars to a 7-car train. It alters the whole question of relative weight if that is taken into account. I have here the figures of the latest steel rolling stock on the District Railway which is just being put into operation. They are as follows:—

Trailer cars per motor car	1
Motors per motor car	2
Horse-power per motor	230
Temperature rise at which horse-power is taken for 1-hour run...	135° F.
Gear ratio	3·37
Diameter of driving wheel	36 in.
Diameter of trailing wheel...	30 ,,
Weight of each motor	6,100 lb.
Weight per rated horse-power	26·5 ,,
Bogie wheel-base (motor)	7 ft. 3 in.
Bogie wheel-base (trailer)	7 ,,
Weight of car complete (motor)	33 tons
Weight of car complete (trailer)	22 ,,
Weight of motor bogie complete	11·4 ,,
Weight of trailer bogie complete ...	3·8 ,,
Weight of motor bogie without motors ...	6 ,,
Weight of car body complete and equipped (motor)	18·2 ,,
Weight of car body complete and equipped (trailer)	14·4 ,,
Weight of equipment complete including motors but not compressors	7·3 ,,
Length of car	49 ft. 9 in.
Width outside	8 ft. 8 in.
Length of bogie centres	34 ft. 1 in.
Floor area	320 sq. ft.

The whole of this is passenger space, except that in the front car of the train a space 3 ft. × 8 ft. is shut off for the motorman. The space available for passengers is thus 99·1 per cent of the total floor space in an 8-car train.

Square feet per ton for motor and trailer car ...	11·6
Square feet per ton for motor car only	9·7
Square feet per ton for trailer car only	14·5
Horse-power per ton of train	8·4

The most severe continuous service on which these trains operate is about 17 miles per hour schedule speed with stops about $\frac{1}{2}$ mile apart.

Mr. Firth. Mr. H. W. FIRTH: The author emphasizes on page 445 the importance of the question to which Mr. R. T. Smith* recently called attention in connection with locomotives, and to which I also referred in the discussion, namely, the characteristic curve of the motor. Mr. O'Brien shows that that is again important, not only in connection with the question of locomotives or the utilization of suburban rolling stock on non-suburban services, but even in suburban traffic where a certain amount of non-stop running is necessary. He refers to the question of strength as regards collision, and his remarks seem to show the importance of keeping down to the lowest possible limit the weight on the underframe—that it is much more important to keep that down than to keep down the weight on the bogies. If that be so, it certainly seems to show that single-phase equipment, which requires very heavy apparatus on the underframe, would be less satisfactory in this respect than systems which place most of the weight on the bogie. The author also gives the capital cost of motor coaches as £70 per ton, and of trailer coaches as £45 per ton. I take it that the difference is entirely accounted for by the electrical equipment. I should like him to tell us whether this is so or whether it costs more per ton to build a motor car than to build a trailer car, excluding the equipment. The light car design which the author has shown is very interesting, but I think it does not give as great a seating capacity as side-door compartment cars do. Thus, the light trailer car of the Lancashire & Yorkshire Railway, if my figures are correct, provides a seating capacity of 1·62 seats per foot-run of train, whilst a side-door compartment car gives a seating capacity of at least 1·8 seats per foot-run of train; moreover, this light car gets that seating capacity per foot of train (which is less than that of the side-door compartments) only by increasing the width of the car to 10 ft., or at least 1 ft. more than usual. I should like to know whether these 10-ft. wide coaches are operated over the same road and at the same platforms as ordinary narrower stock. If this be the case, how are the platforms arranged so as to deal with both types of coach? The author makes a point that the gauge of the rolling stock should not be restricted to the limiting point of the loading gauge of the line. That is all right in case the limiting point of the loading gauge is in some out-of-the-way portion of the line, but there are a large number of places in the very centre of the heaviest suburban traffic in London where 10-ft. cars could certainly not be run. I think the seating capacity per foot-run of this car does not show up as favourably as I thought it might compared with the side-door arrangement. As regards the weight per seat, or number of seats per ton,

* R. T. SMITH. Some railway conditions governing electrification. *Journal I.E.E.*, vol. 52, p. 293. 1914.

rth. this car is, so far as I know, far ahead of anything that has ever been built. The author points out that the side-door car is much less inherently strong than the end-door car. I should like him to tell us the time that it takes to empty a full car of this description on its arrival at a terminus. I think it will be found that quite a long time is taken to empty one of these cars. It may be all right with the frequency of service with which these cars have to contend, but in some cases the frequency of service is so great that the utmost speed is required in loading and unloading passengers. I notice in Fig. 6 that the author shows two designs with additional doors in the sides of the car as well as those at the ends. Does not this increase the weight of the car over the weight of those with end-doors only? Also, is there any advantage from the point of view of the passenger in this arrangement over the arrangement shown in the first two diagrams? It seems to me that they can be unloaded more quickly, but I wonder whether the author can give us any results from actual operation. With regard to the question of bogies, I notice the wheel-base of the new bogies is 10 ft. I think I am right in saying that the original Lancashire & Yorkshire bogies had an 8-ft. wheel-base. Has this increase in wheel-base been due solely to considerations of providing satisfactory running for light cars? In a paper * read last month by Mr. Willox before the Institution of Civil Engineers the very great importance of wheel-base in regard to the question of rail wear has been pointed out. I wonder if the author could give us any information as to rail wear with relative wheel-bases, and tell us whether the question of rail wear influenced the choice of wheel-base. Or was it chosen solely with a view to improving the riding of the cars?

parks. Mr. J. B. Sparks: In discussing methods of reducing the weight of motor coaches, the author presents much information of value, but I consider that the calculations which he gives on page 447 largely exaggerate the importance of such a reduction in weight, and, moreover, are worked out on a wrong principle. The author has assumed that the costs of energy, and of repairs, maintenance, etc., vary *pro rata* with the weight of the coach, but I submit that these costs will not vary in any such proportion, and that the cost per ton will increase for any reduction in the total weight. Further, I believe I am right in saying that the weight of all types of electric rolling stock has largely increased since electric traction was first introduced, it having been found that the more substantial construction obtained with an increased weight reduced the maintenance. Provided the required strength is obtained, it is certainly advantageous to avoid excessively heavy cars, but I submit that it would not pay to increase the cost of rolling stock by 10 per cent in order to save 4 per cent in weight, as the author suggests. With regard to the importance of weight reduction as affecting energy consumption, I have made the following estimate as to what reduction in total cost of working a railway would result from reducing the weight of the motor coaches by as much as 10 per cent. Taking the cost of locomotion (that is the cost of operating the trains) as 30 to 40 per cent of the total cost of operating the railway, and the cost of energy as 50 per cent of the cost of locomotion, the energy accounts for from 15 to 20 per cent of the total cost of working the railway. Owing to the various losses in the electrical system and the energy required for overcoming wind resistance, etc., we may assume that a reduction of 10 per cent in the weight of the rolling stock will only reduce the energy consumption by 5 per cent. This saving of 5 per cent in energy consumption would probably reduce the generating costs by not more than $2\frac{1}{2}$ per cent. As stated above, the energy cost amounts to from 15 to 20 per cent of the total cost of operating the railway, so that if this be reduced by $2\frac{1}{2}$ per cent the reduction on the total cost of operating the railway amounts to only 0·375 or 0·5 per cent. This reduction of less than 0·5 per cent in the total cost does not seem to bear out the author's figures. I should like to know if I am right in assuming that he takes the expenditure on energy consumption, maintenance, etc., *pro rata* with the weight of the coach. [Mr. O'Brien: Yes, that is quite correct. I estimate that if the weight of the coach be reduced from 10 tons to 9 tons the cost of repairs should be reduced from £50 to £40 per annum.] I submit that this is a wrong principle on which to estimate this saving, and that the reverse to what the author suggests is more likely to occur. Mr. Sparks.

Mr. R. H. Burnett: A similar subject was discussed at the Institution of Civil Engineers only the other day when a good deal was heard about the great wear of rails, although nothing was said about the tyres. I fancy there must also be a great wear of tyres. In the papers that were read before the Institution of Civil Engineers the authors had investigated most carefully—I may say microscopically—the proper composition of rails to withstand the wear that takes place. I ventured to point out in the discussion on those papers that I thought the ingenuity displayed in determining the chemical composition of rails might be better expended in investigating the cause of their wear, as in my opinion it was due to a very great defect in the gear through which the electric force is transmitted to the wheels. I will confine my remarks to-night to only a few points, and I may start by mentioning that my experience of 40 or 50 years ago on the Metropolitan Railway enables me, I think, to speak on the very points that are being raised by the paper to-night, because of my having had charge for eight years of the rolling stock and the permanent way in steam locomotive days. We did not then work the length of line that is being operated now; the total length of the Metropolitan Railway, the District Railway (which we also operated and maintained), and the other branches of the Metropolitan Railway, was then only 25 miles; but I had some experience of what I may call the intense traffic that is peculiar to electric traction, because of the short distances between the stations, and such questions as starting and stopping quickly, rounding curves, etc., were even then very much to the fore. I wish in the first place to emphasize Mr. Casson's remarks with regard to the need for solidity of the bogies through which the electric force is transmitted to the rails. My observation of the rolling stock of the Metropolitan and District Railways has made me feel that in the attempt possibly to get lightness the very large amount of work that is being done by these bogies has not been taken into account. Taking the analogy that the first speaker made about the bogies of steam locomotives, although they have no driving to do they would soon go to pieces if they were constructed in the more or less—I do not like to use the phrase—flimsy way that I observe. It is very important Mr. Burnett.

* W. Willox. Rail-steels for electric railways.

Mr Burnett. that the bogies should be substantial in view of the enormous force that is given out in propelling the train. I think any saving in the weight of the bogies themselves is quite a mistake. The direction in which one should go is rather to make them more solid to stand the wear and tear upon them. Another important question is the length of wheel-base. To my mind the wheel-base is too short. Theoretically a short wheel-base is the right thing, because it tends to reduce what I may call the "scissor" action between the guiding flange and the high rail. I watched very carefully the action of the various types of bogies running over the Metropolitan Railway in my time, because the wearing away of the rails and flanges was a very important question, and I am satisfied that a long wheel-base is infinitely better in practice than a short one, because it compels the bogie to set itself more correctly to the curve and reduces the flange friction and the wear on the side of the rail. I notice that various figures are given in the table on page 454 for the bogie wheel-base, under the heading of "Trailer cars." I am glad to see that the bogie wheel-base in No. 1 is 10 ft. as compared with 5 ft. in No. 2, and 5 ft. 6 in. in No. 6. I am quite sure that the bogie with a 10-ft. wheel-base is better than a bogie with a 5 ft. or 5 ft. 6 in. wheel-base; in fact I think one need not be afraid of going up to 12 ft. With 40-ft. carriages we had a 20-ft. steadying wheel-base—a most important feature for ensuring steady running on the *straight* portions of the lines—and the cars went round the curves with perfect ease when properly guided by radial axles in front and without any wear on the wheel flanges.

The other point that I should like to mention is the diameter of the wheels. The larger it is the better. Mention was made at the Institution of Civil Engineers the other night of the sacrifice of seating accommodation if larger wheels are used. We had wheels 3 ft. 6 in. in diameter and did not sacrifice any seating capacity. I really do not understand why at least 3 ft. 6 in. wheels should not be used on electric rolling stock. Even if it meant sacrificing some seats I believe it would pay. Who would ever think of running a locomotive—of course there is the reciprocating action with it which I admit does not occur in electric traction—with small wheels like those under an electric train? Such a locomotive would knock itself to pieces in no time. It is therefore very important to use wheels as large as possible even if it means sacrificing some seats or raising the floor of the carriages. What does it matter if people have to step a few inches higher than they have to do at present? Another point emphasized in the paper read before the Institution of Civil Engineers was the difficulty of carrying the motors on springs. I am not an electrical engineer and it is not for me to suggest how the thing should be done; but why not attach the motors to the bodies of the vehicles and drive the axles of the carriages through gearing or in some other way, the weight of the motors being carried, not on the axles, but on the body of the car? The weight would then be carried on the springs, which cannot be the case when the motors are attached direct to the axles of the driving wheels.

Mr. Mason. Mr. C. L. MASON: As a representative of the carriage department I have been very much interested in this paper. In particular I was astonished to see the figure that was given for the saving that is effected by doing away with the superfluous weight of carriages. The trend of modern carriage design is always towards a heavier vehicle, and I think the reason for this is that a lighter coach built on the present lines will not stand up to modern traffic conditions. Secondly, the public demand greater comfort, which means less seating capacity per vehicle or greater weight per passenger, and there is also the steadier riding that is obtained by a heavier vehicle. In designing a lighter coach the carriage superintendent would have to be careful not to increase unduly either the first cost or the cost of maintenance, as it is by these figures that he is judged. The saving in haulage, etc., effected by reducing the weight, referred to by the author, does not show in the balance sheet as such, and would not perhaps be so apparent to the general manager and the directors, and by them credited against the increase in first cost. Naturally, therefore, if the carriage superintendent finds that the lighter vehicle causes the maintenance charges to increase, he is apt to build a heavier vehicle in order to make sure of keeping down his departmental costs. I should like to ask a question with regard to the paragraph at the bottom of page 447, to which a previous speaker has referred. I have not been able to follow the statement that "it becomes therefore a commercial proposition to spend as much as £185 per motor and £145 per trailer in labour and material in order to save a ton in weight." As I understand it, it should be the total saving per annum by omitting this ton of weight, multiplied by the life of the coach; that is to say, so much is saved in first cost, so much in the wear of the permanent way, and so much in hauling the vehicle, and the annual saving multiplied by the life of the vehicle will give the amount that might be spent in getting rid of the unnecessary ton. If we take, say, the £19 per trailer and divide it into the £145, or the £25·5 and divide it into the £185, it gives a figure of somewhere about 7 or 7½, which from my reasoning would appear to be what the author assumes the life of the electrical coach to be, so that I can only presume I have misunderstood his calculations somewhere. Further, he says on page 446: "It is not a difficult matter so to design the ends of the underframe as to prevent over-riding of one underframe upon another." I should like to ask him whether he knows of a suitable device that will prevent the over-riding of an underframe fitted with buffers, such as we have to use on the London & North-Western Railway.

Mr. Bowden. Mr. J. BOWDEN: Comments have been made on this paper by locomotive, carriage, and electrical engineers, which suggests that this series of papers on electric railway work is bringing together that combination of experience in the development of electric rolling stock which has hitherto been rather conspicuous by its absence. On page 454 the author states that "it will be realized that the question of weight has not had the same attention given to it as the question of equipment." There can be little doubt of this, mostly due to the new conditions and problems raised by electric traction apart from the design of motors and control gear. The design of rolling stock for heavy electric working has been largely a question of trial and error; this paper points out a better way and also the importance of weight saving, to which the remarks of previous speakers suggested opposition. Surely the factor of intrinsic strength which the paper so strongly emphasizes has escaped their notice. We cannot be content with anything but rational design, and we are led thereby to use

Mr. Bowden. only such materials as make for weight reduction. If strength efficiency be thereby sacrificed, the design is not rational. Materials have so far progressed during the last 10 years that alloys of steel and bronze can now be made with such physical properties, that but for their use the hulls of large ships like the *Mauretania* could not have been built within the tonnage limits now common to that class of ship. On similar lines the operating costs of electric traction can be economized. I am in accord with Messrs. Burnett and Casson as to the desirability of following locomotive practice in regard to design, materials, and workmanship of trucks. Early locomotive engineers soon found it necessary to construct frames which, in addition to being suitable as a carriage, were sufficiently rigid to take the stresses of the engine itself and of starting and stopping. The motor truck mentioned in the paper is equipped with two motors of 250 h.p. normal rating, and capable, no doubt, of 50 per cent overload on occasion. Thus the truck may have to stand stresses incidental to 750 h.p. at starting, and equally heavy stresses on stopping. For such service a mere carriage truck is not sufficient, and failure to appreciate this has proved expensive, as many of us know. Judged by the heavy service conditions which obtain in London the truck shown in the paper appears to be light. The vacuum brake is used, and this affirms the suggestion. I would ask the author whether that brake retards so heavily as is required for the Metropolitan and District Company's services where short runs and 20-second station stops are required to meet the time-tables of to-day. The large vacuum reservoirs suggest difficulty in this respect. In truck details I notice that the journals are without button heads, side thrust being taken on the ends of the axles by bearings provided with means of adjustment. This arrangement is comparatively new in this country, though common in Continental practice and in America, but without the adjustment. As Mr. Burnett said, the longer wheel-base eases the side pressure on axles, and end wear is particularly troublesome on short-wheel-base trucks. The gear wheel is bolted to an extension of the wheel boss—I presume in halves. [Mr. E. O'Brien : It is pressed on.] If bolts are used why not take advantage of split gears and avoid pulling off wheels when renewing gears ?

Seating and door arrangements have been discussed at some length, and I would refer to experience of both car and compartment stock working together. Car stock only was installed on the electrification of the Metropolitan Railway, and later Mr. C. Jones converted several existing compartment trains built for steam service and of comparatively recent construction ; the trailers were fitted with train lines and the end vehicles were mounted on new underframes and motor trucks ; fireproofed compartments were provided for control gear and motormen. These trains are greatly appreciated by the traffic department and travelling public alike. Compared with car trains, even those fitted with centre doors, the side-door train loads and unloads faster, the public prefer the privacy, there is less difficulty with draught, and the doors being fitted with slam locks and suitably hung give no trouble or delay in opening and closing. These compartment coaches are easier and quicker at stations than the car trains working on the same service, and the superiority of the old side-door arrangement has been fully demonstrated on the Metropolitan Railway. There is, moreover, the advantage of utilizing existing stock which by obsolescence might become a heavy charge against electrification. Mr. Bowden

Dr. S. P. Smith : On page 445 the author draws attention to the very important matter of the different services for which motor coaches have to be equipped, such as low-speed city traffic and high-speed suburban traffic, which makes it troublesome to obtain the best conditions for both classes of traffic in one and the same vehicle. The result is that a compromise has to be accepted both in the motor characteristics and in the gear ratio. Now this is probably the cause of a lot of the trouble that is experienced on the suburban service, owing to the excessive strains that are set up thereby. It would be far better if there were more elasticity in the method of speed control, for we could then suitably meet the various conditions of working. At present the standard method is to use the series-parallel method of control and quickly bring the train up to a fairly high speed ; it is then allowed to coast a certain distance, depending on circumstances, and is finally brought to rest as quickly as possible. This is doubtless rather bad for the equipment, but as long as we are limited to the series-parallel method of control we cannot well avoid working in this way. If, however, we can get more elasticity into the speed control we can get characteristics which are more suitable for both low and high-speed traffic. The recent developments in the design of traction motors tend to show that instead of having only two economical running speeds we can have any desired number, though probably only three or four would be used owing to the complications of the controller. This elasticity is obtained by means of field control produced either by placing the poles in parallel or by diverting the field current. The possibility of field regulation is a consequence of the introduction of interpoles in traction motors. So long as interpoles are not used, one of the most important things that the designer has to bear in mind is commutation, which practically determines the flux ; but as soon as the interpole is introduced he can vary the flux as he pleases. The result is that the same heavy starting is no longer necessary to produce a high acceleration, because a much stronger field can be used. It is then possible to run up to whatever speed is suitable and to remain at that speed for a longer period, instead of running to a high speed and then coasting. In this way there are not the same heavy demands on the station either when starting or running. On reaching the suburban line the driver can then notch up to a higher speed when required. By thus taking full advantage of the interpoles, which at present seem to be advocated chiefly for producing good commutation, it is possible to improve the service very considerably by increasing the number of economical speeds ; at the same time the starting losses, the maximum electrical demands, and the mechanical stresses will all be reduced. The future will probably show that series-parallel control alone is but one step in the right direction. Dr. Smith.

Mr. F. W. Carter : There are only a few matters that I wish to mention in connection with the paper. The first has reference to Fig. 1, which shows the resistance to motion of a two-coach train. Train resistance is a subject on which no two people ever seem to agree, and I must Mr. Carter.

Mr. Carter say that I consider the curve given in the paper is very high. At 35 miles per hour the resistances are shown as approximately $18\frac{1}{2}$ lb. per ton; I think this is higher than would be expected even for a single coach of 40 tons' weight. I wish therefore to ask the author what is included in the train resistance, because there are practically two train resistances that appear in electric railway work. One is train resistance when power is on, and the other the train resistance when the train is coasting. In the latter, the motors are being driven, and in addition to the true train resistance there is axle-bearing friction, gear friction, armature-bearing friction, brush friction, and wind friction in the motors, all of which appear as resistance to the motion of the train. This may amount to a large percentage of the whole, and in one case that I recently investigated, viz. that of a heavy interurban car of the American type, weighing about 25 tons, having a 4-motor equipment, and running at about 20 miles per hour, the effect of the friction due to the motors when the car was coasting was about 4 lb. per ton. If, then, the train resistance as deduced from the slope of the coasting curve is, say, 16 lb. per ton, only about 12 lb. per ton of this is true train resistance, and the rest is friction which only appears when the car is coasting, since all this friction is attributed to the motor when power is "on." It would not be practicable to attribute the motor friction to train resistance when power is "on," as the gear losses necessarily depend on the power that is passing through the gears. I wish, therefore, to ask the author whether in Fig. 1 the motor friction has been subtracted, leaving the true train resistance, or whether the motor friction is included, which may account for the curve being so high.

I have long contended that unnecessary weight should be saved in trains intended for suburban services, and am therefore gratified to find that the author takes the same view. The value of the saving does not amount to much for long-distance services, as it is only the fact that frequent stops are made that makes a saving in weight result in a commensurate saving in energy. As I read the paper I do not think the author is suggesting that weight should be saved at the expense of strength in the coach, as many speakers seem to have assumed. I am sure the author fully realizes that the saving must not be such as will diminish the strength, but must be effected by more careful choice of material, or by cutting down weight where it is not necessary for strength. Any saving in weight that can be obtained in this manner is justifiable and good economy, but a saving which results in a sacrifice of necessary strength would probably cost more in maintenance than is saved in power. In common with several other speakers, I do not quite appreciate what the author intends to convey by the paragraph at the bottom of page 447, on the subject of the yearly saving due to a saving of weight. It seems to me that it is not right to take maintenance at so much per ton when the question of weight itself is under consideration, because the saving in weight will not necessarily result in a saving in the cost of maintenance. I should say the only saving to be expected would be the power saving of £12 10s. per annum. The only other point to which I wish to make reference is in connection with motor weight. This is a matter that has come forward during the last few years, and it is now usual to design motors with this feature strongly in view, and to arrange induced ventilation to carry away the heat in order Mr. Carter that as light a motor as possible for the power may be obtained. This is done with the special object of doing away with unnecessary weight, and it is quite in accordance with the author's views on the subject.

Mr. W. A. A. BURGESS (*communicated*): Although the Mr. Burgess author has dealt rather fully with the reduction of dead weight, he does not refer to the importance of reducing to a minimum the proportion of the motor weight that is directly borne by the axle. This proportion of course very considerably affects the hammering action at rail joints and crossings, and therefore the upkeep of both track and tyres, and to a less extent that of the rolling stock as a whole. The "wheelbarrow" method of motor suspension shown in Fig. 8 is undoubtedly preferable to suspending the whole of the motor weight from the axle, but even so more than half the weight of the motor has still to be carried by the axle. It appears very desirable therefore to aim at the suspension of the motor from the sole plates at a point as near as possible to its centre of gravity, and even though this is by no means easy owing to the necessity for keeping the motor as far as possible below the underside of the car floor, I consider that it will be found practicable in many cases. As the sliding movement of the motors would be doubled by this method, owing to the radius being halved, it would probably be found most satisfactory to suspend the motor by pivoted links which would allow this movement to take place without the necessity for a special bearing sliding in guides on the sole plates. As to the ventilation of coaches, an objection to the method of introducing fresh air at the bottom of the coach and there warming it is the amount of dust that would be kept in suspension in the air; for as users of some of the types of domestic radiators now on the market are painfully aware, there is always an impalpable dust which only the frequent use of a vacuum cleaner can keep down, and which is very perceptible in the rising current of warm air from radiators standing directly on the floor. I therefore suggest that the process be reversed and the air extracted from the carriage at the floor level, fresh air slightly warmed and properly diffused being admitted at the top of the carriage. The heat required by varying outside temperatures should preferably be provided by heaters suitably distributed under the seats or in the footboard and controlled by the passengers. With reference to carriage lighting, owing to the proximity of the roof to the level of the eye, semi-indirect lighting seems particularly suitable, and with a matt-white roof-surface a plain inverted conical shade of white opal glass suspended directly below the lamps will be found to give a pleasing effect with lamps of moderate candle-power.

Mr. W. Y. LEWIS (*communicated*): In my paper before Mr. Lewis the Society of Engineers in May, 1912,* I emphasized the desirability of (1) low weight of rolling stock per seat provided; (2) graduated acceleration and deceleration so as to permit of mean accelerations and decelerations several times greater than was customary; (3) regeneration during deceleration. I welcome Mr. O'Brien's paper as dealing with (1), and hope that forthcoming papers relating to electrification problems will discuss the evidently more promis-

* W. Y. Lewis. Intermittency: its effect in limiting electric traction for city and suburban passenger transport. *Society of Engineers, Transactions for* 1912, p. 121.

Lewis. ing fields, (2) and (3). It seems a pity that the author has not summarized the possibilities in the field that he had explored, by indicating, if only approximately, the extent of the weight reduction attainable by resort to the refinements described. Perhaps he would in his reply state this for the case of the latest Lancashire & Yorkshire Railway train comprising, say, two motor and two trailer cars, which presumably would be capable of the 30 miles-per-hour schedule speed with one stop per mile service mentioned in the paper. It would also be useful if the tables were amplified, especially as regards average weight per seat in a given train with or without refinements. From the paper one might expect that a saving of at least 10 per cent in dead weight per seat is attainable; but this is misleading. The allowance of only 4 sq. ft. per passenger is too low to ensure the comfort which the public demands and which engineers should strive to give. Recently the Midland Railway introduced a new train on the Southend service having six-seats-per-side compartments on approximately this basis, and the patrons of the line are strongly protesting against this bare allowance. If the wide coaches suggested would involve track slewing and platform widening, the capital cost thereof might easily become a sufficiently serious consideration to outweigh the advantages to be gained by saving weight. Analysing the paper, I have found it difficult to account for anything like a 10 per cent saving of weight by the refinements set forth. Assuming that the advantages of extra wide coaches be offset by track widening, etc., I deduce the following results:—

Item	Weight Saved	Extra Cost
Al. roof instead of steel ...	0·5 ton	£60
Al. panels instead of steel	0·5 ,,	£36
Al. seats instead of cast iron	0·75 ,,	£70
Special steel underframe	1·00 ,,	£48
Sundries, say	0·25 ,,	£25
Totals	3·0 tons	£239

Against this there is the possibility of an increase of dead weight on account of bows, double brake-blocks, etc., amounting to at least $1\frac{1}{2}$ tons and involving extra cost; but other items not included above, owing to insufficient data being given in the paper, may possibly balance these. Assuming this to be the case, it seems therefore that in the 67-ton Lancashire & Yorkshire motor coach costing £70 per ton the dead weight could be reduced to 64 tons (a $4\frac{1}{2}$ per cent weight reduction) at an extra capital cost of say £220 (4·7 per cent extra), allowing £19 for the saving in labour cost due to lighter material. This means an increase of the cost per ton from £70 to £77, or 10 per cent. The author appears to suggest that the saving of 3 tons of dead weight would warrant an increase in capital expenditure from £70 per ton to—

$$\frac{(67 \times 70) + (3 \times 185)}{67 - 3} = £82 \text{ per ton}$$

(*i.e.* a 17 per cent increase). His argument taken in the case of a trailer car is even more startling, since a similar 3-ton saving of weight would, according to the paper, warrant an increase of the rate per ton from £45 to £71 (*i.e.* 57·5 per cent). The deductions on page 447 do not seem to be sound, and it is to be hoped that they will be satisfactorily explained or modified in the author's reply. The tendency in the design of electrically operated rolling stock is towards increased rather than decreased weight, and it is significant that the latest example of Lancashire & Yorkshire rolling stock described in the paper and presumably tabulated in column 1 of the tables is exceptionally heavy. It remains incumbent upon traction engineers to reduce both the weight and the capital cost. To reduce only slightly the dead weight and thereby considerably increase the capital cost will not help matters at all. In conclusion, I may perhaps be allowed to point out that the prospect of much improvement in the direction of weight-saving cannot make one very hopeful of finding the better solution of traffic problems in the electric train system. I have indicated in the above-mentioned paper that by resorting to the continuous plan of operation (or, if need be, semi-continuous plan) as against the present intermittent plan, the weight per seat can be reduced from 1,200 or 1,400 lb. (as instanced in the Lancashire & Yorkshire rolling stock) to about 400 lb. in the electro-mechanical system recently put forward by me. As to this, I may say with Mr. Hobart, who had deeply investigated it, that a schedule speed of 30 miles per hour with one station per mile in the outskirts and a 16-miles-per-hour schedule speed with 4 stops per mile in urban districts, can be far more easily and cheaply attained than by the electric train system.

Mr. Baker. Mr. C. A. BAKER (*communicated*): The author refers on page 447 to the question of a railway company producing its own electrical energy, and he puts forward some reasons in favour of its doing so. I should like to remind members that in the recent paper by Mr. Roger T. Smith it was pointed out * that "the generation of electrical energy and its supply is a business in itself," continuing generally to prove that it is more advantageous for a railway company to purchase than to generate electrical energy. I entirely agree with Mr. Smith's opinion, and would condemn the establishment of the two new generating stations now under construction for London railway companies as being encumbrances for many years to come upon their respective proprietors. In neither case has it been possible to select a site that may be considered ideal or even mediocre; electrical energy could be purchased in any quantity that the companies might respectively require, from established undertakings which have reputations for reliability and economy, and at prices that, with the available diversity factor, must be better than those at which a solitary station can in the long run produce. No better object-lesson is necessary than the case of London with its 50 or more generating stations which 15 or 20 years ago were established with the guidance of the most enlightened expert advice and commercial knowledge that could be obtained, and now the question arises what is to be done with them. History will for ever repeat itself, developments in electrical generation have been and will be rapid, and unless it is impossible for a railway company to purchase the energy that it requires, there can scarcely be sufficient justification for the equipment

* R. T. SMITH. Some railway conditions governing electrification. *Journal I.E.E.*, vol. 52, p. 297, 1914.

Mr. Baker. of a generating station and the establishment of a new staff in connection therewith. The author further adds that "the operation of generation, etc., falls naturally within the province of the Chief Mechanical Engineer's Department"; here again I disagree with him. The electrical department should be independent and in charge of a responsible electrical engineer with the right to put forward his own views from his own standpoint, having primary regard to the utmost efficiency of the undertaking unhampered by considerations which a mechanical engineer, who is dealing primarily with duties of another character, may or may not see fit to endorse. As to "the changes of policy that occur with municipal stations" to which the author refers, I fail to recognize what undertakings he has in mind, those stations of the classification suggested in and around London having nearly all progressed most favourably from their earliest days.

Mr. O'Brien. Mr. H. E. O'BRIEN (*in reply*): Mr. Casson suggested that in Fig. 2 the horizontal scale should be "time in seconds" instead of "speed in miles per hour." That is quite right, and the suggestion will be carried out. In Fig. 3 the energy is the energy input into the car and not the output from the motors. With regard to Fig. 4, Mr. Casson suggested that an even load would not be obtained when there are 56 trains running. I must admit that he is correct in that. It would be possible to have 1,000 trains and not obtain a level load. What I wished to indicate was that when one gets as many as 56 trains on a system one is beginning to approximate to a level load if batteries are not used. He is quite right in raising that point, and I should have added that explanation to the paper. Mr. Casson and various other speakers have queried the propriety of basing the cost of repairs on the tonnage. Different engineers have different experiences, but our experience in the North of England has tended to show that the repairs do depend very largely on the tonnage of the cars.

Replying to Mr. Mason at the same time on that point, I should like to say that I speak as a carriage and wagon man and as a locomotive man more than as an electrical engineer, and taking the period of the last seven or eight years the very light cars have shown themselves to be exceedingly economical in maintenance, and the heavier cars, even though the design has been strengthened, have proved heavier in maintenance. It is to a certain extent a matter of design. One designer places his material in one position and another designer in another position, better results perhaps being obtained in one case than in the other. I quite understand that under certain special conditions it may be otherwise, as for instance on the Central London Railway.

Generally speaking, the maintenance does depend entirely on the weight; and the weight of the body is the most important part of the weight of the car, because on it depends the weight of all the other parts. I agree that as far as the body itself is concerned a very heavy rigid body will require less maintenance than a very light flexible body, but a light body can be designed which will still be very rigid, and the maintenance of which will be practically the same as that of the heavier body.

Supposing that the weight of a car is increased from 30 tons to 40 tons, in the first place the axle loads are increased; that means to say that larger bearings are necessary. Even if the bearings are enlarged so as to obtain the same bearing pressures, they will only run the same length of time as the smaller bearings, and when they are renewed it is a larger bearing that has to be renewed. The same remark applies to the tyres. Mr. O'Brien.

The cost of tyre renewals will increase even more in proportion, because the tyre has practically line contact with the rail, and consequently the greater the intensity of pressure (we are limited practically to four wheels per coach on an electric coach) the quicker the tyres wear out. When it is necessary to re-tyre, the old tyre has to be scrapped, so that the cost of repairs increases more than proportionately. The same remark applies to the armatures. There is a larger coach and a larger motor, consequently a larger armature with more copper in it. The life of the insulation will be just the same in both cases; but when it comes to rewinding, larger coils and more insulation have to be renewed, so that I do not feel inclined to recede from the position that I took up, namely, that the cost of repairs is very nearly proportional to the weight of the cars.

In the next place Mr. Casson complained of the small seats provided in Fig. 6. I think it is a good point that where passengers are getting in and out every one-third or half a mile a little more knee room is probably required than when the stoppages are further apart; but I hope Mr. Casson will pay us a visit in the North. It is a rather out-of-the-way place and difficult to get to, but I think if he will get into these cars he will find that they are not as uncomfortable as they seem. I consider 16 in. is quite a reasonable accommodation for anybody, and I think that if the 4 ft. 11 in. centre is actually tried it will be found that it allows one to sit quite comfortably.

Mr. Firth pointed out that the side-door car gives greater seating capacity. That is perfectly correct. I think that about 20 per cent more seats are obtained in a side-door car; but if passengers are to be taken 20 to 25 miles out from the terminals, which is what is wanted if possible, as Mr. Roger Smith recently pointed out in his paper, I do not think the side-door car is suitable. It may be suitable in certain districts—it certainly is not suitable in the North of England, with an exposed coast like the Lancashire coast, and it is found that when once accustomed to it the public prefer the corridor car; so much so, that we actually have complaints when corridor cars are removed from a service for repairs and compartment stock has had to be substituted. The circumstances are different in the South, and it is possible there, with the shorter distances between stations, the milder climate, and the shorter runs, that the side-door car would give satisfaction from the point of view of comfort.

It certainly does not give the management of the railway satisfaction as regards the platform staff that they have to keep, because if there are 8 doors per car to open and shut every time, unless this is left to the passengers, it involves keeping a considerable number of men on the platforms for the purpose of doing that work. The time taken to empty one of these corridor cars with end doors when it is crowded is a smaller time than it takes for the motorman to get out of his compartment at one end and walk to the other to reverse the train; and unless the traffic has become so dense that a motorman will be waiting on the platform to step into the other end of the train—that may be the case in London, but it is not the

case as yet with us in the North—unless that point has been reached, the train can be emptied without involving unnecessary delay at the termini.

It was stated that the doors in these corridor coaches were too narrow. The doors are not narrow but exceptionally wide—sufficiently wide, in fact, to allow two people to enter or get out abreast. The door opens in the direction of the exit traffic, and the results obtained in practice are very satisfactory.

The question of the vacuum brake was raised by several speakers. There is no reason—if there is, I should like to know what it is—why the same retardation should not be obtained with the vacuum brake as with the Westinghouse brake; and the retardation on the Liverpool & Southport line is actually greater than on the London lines.

In the case of the vacuum brake a lower pressure, 11 or 12 lb. per sq. in., is used. It is purely a matter of cylinder diameter. In the case of the vacuum brake one has a 21-in. brake cylinder, compared—I am not familiar with the dimensions of the Westinghouse brake—with probably an 8-in. cylinder in the case of the Westinghouse brake. The question of the rapid production of the vacuum is certainly a difficulty. That is why I said that there was a field for a high-speed vacuum pump. The vacuum pumps that are used at present are low-speed and more or less inefficient machines, but even with them it is quite possible to produce a vacuum on a 5-car train within 15 seconds so that 20-second stops are quite practicable. The rapid raising of the vacuum is effected partly by the use of the high-speed valve on the train pipe—which incidentally ensures graduated application of the brakes—and also by having vacuum reservoirs to which the pump is connected while the train is running between the stations, the vacuum in the reservoirs being then used for re-creating the vacuum in the train pipe.

The table on page 453 would have been very much more useful if the names of the railway companies had been given: I was anxious to give those names, and received a general consent with one exception; consequently I had to leave the table as it stands.

Mr. Firth drew attention to the importance of the motor characteristic. I am very glad that he did so because it is one of the things that wants to be very carefully considered in designing rolling stock for suburban services, where it is very difficult to meet the varying requirements.

Then as to the question of collisions, the weight of the underframe should be a minimum. I do not think it is possible to prevent telescoping, but it is possible to go a long way towards preventing it by providing very strong pillars at the ends of the underframes, and by so doing the effect of the telescoping will in many ways be minimized. Collisions at high speeds, I believe, will always cause telescoping, no matter what we do; all that I wished to point out was that the rational way to meet the possibilities of collision was not to increase the weight of the whole car, and thus introduce a perpetual charge, but to try and design ends so that the underframes would not lift over one another, as far as could be done without seriously increasing the weight; and also to do what is being done in America, that is, fasten the underframe on to the bogies so that part of the energy of the collision will be absorbed in tearing away the bogie from its attachment to the underframes. As to the saving effected by weight reduction, I said "it becomes therefore a commercial proposition to spend as much as £185 per motor and £145 per trailer in labour and material in order to save a ton in weight." I think I should have omitted the word "commercial." I should have said "no loss will be involved if one spends as much as £185." I look at it from this point of view: that one could borrow £185 at 5 per cent and could provide a 5 per cent depreciation fund for renewing that £185 in approximately 17 or 18 years. That would cost £18·5 per annum, which was exactly the saving which would result by reducing the weight by one ton. Of course it would not really be profitable to spend £185, but one would not lose by spending that sum.

Mr. Mason suggests that the life of a coach should be taken into account, but he will see that it is done when the transaction is looked at in this particular way.

Mr. Sparks seemed to say that because the saving effected was only a small percentage of the total cost of traction, it was therefore not worth considering. That of course is a proposition to which nobody engaged in the practical maintenance of rolling stock could assent. It is only by grasping at every little economy which can be effected at not too great a capital cost that the cost of operation could be reduced in such a way as to produce satisfactory results.

In answer to Mr. Firth, the 10-ft. rolling stock operates over the same roads and platforms as all other stock, and there is no difficulty in effecting this.

Mr. Firth and Mr. Burnett mentioned the long wheel-base. The 10-ft. bogie of which a drawing was given in the paper was designed partly to minimize the rail wear and partly to provide for larger motors. Those objects were not entirely attained by that bogie, because the greater weights of the motors negatived the increase in the wheel-base; and the wear on the tyres, and also presumably on the rails, with that particular bogie was just as great as on the shorter wheel-base bogie that preceded it.

Another speaker criticized the bogie as being apparently of too light a construction. It is difficult to judge from a drawing, but actually the bogie is of too heavy a construction. It is quite correct as an example of design as far as it is shown in the paper, but it is not correct in the matter of weights; that is to say, the frames, the transomes, and the bolsters, could all have been made much lighter, and will be made lighter in subsequent bogies. This bogie was constructed throughout with the ordinary mild steels hitherto employed in bogie construction; but by the use of high-tensile alloy steels, properly heat treated, a saving in weight of probably not less than 25 per cent could have been effected.

In order to design a satisfactory electric bogie, as was pointed out by one speaker, it is not a matter of getting a heavy bogie, it is a matter of placing the material in the right place. What is wanted is to get ample bearing surfaces on the journals and ample bearing areas on the faces of the axle-boxes, so that there will be no heavy wear on the horns. It is a question of using one of these high-tensile steels and placing the material in the right place, seeing that the bogie is well trussed and that proper diagonal pieces are introduced so as to secure its rigidity.

I quite agree with Mr. Burnett that the bogies must be of strong construction and that the wheel-bases should

Mr. O'Brien. be as long as possible. There is no doubt that the larger the diameter of the wheels the better.

Though it is not referred to in this paper, I do not see why in the case of electric locomotives the bogies should not have wheels as large as 4 ft. 6 in. or 5 ft., or even a little larger. It is practically impossible to have such large wheels on passenger stock, because the loss of seats would be serious. The wheels would interfere with the body of the coach to such an extent that I think more revenue would be lost by the lack of seats than would be gained in maintenance with the large wheels. But with the electric locomotive I see no reason why the bogie wheels should not be very much larger than they are at present.

One of the speakers asked how much of the cost of the cars was due to the electric equipment and how much to the actual coaches, *i.e.* he wanted to know whether the trailer coach cost as much as the motor coach to construct. The motor coach is more expensive to construct than the trailer coach, because it is necessary to provide accommodation for the tractors, attachments for resistances, and heavier bogies; but as far as the actual carriage work is concerned, the cost is approximately the same.

Dr. Smith pointed out the objection to series-parallel control, and suggested that by using field control the peaks on the power station could be very largely reduced. I am not a motor designer, but I thought that we already used practically as strong a field as was possible during the acceleration period, and it certainly had not occurred to me that by the use of interpoles we could enormously strengthen the field and reduce the starting current correspondingly.

The proposal to make the motor cars more flexible, that is to say more adaptable to different services by means of field control, is worth considering, and in many cases it will pay to adopt it.

Mr. Lewis suggests that there is a more promising field in graduated acceleration and regeneration during deceleration than in reducing the weight of the rolling stock. He further suggests that weight reduction is attained by resorting to refinements. I cannot admit that the plain straightforward substitution of lighter and stronger materials is in any way a refinement; it is merely proceeding on rational lines. He is mistaken in assuming that I have stated that the actual instances which I have given where weight could be saved meant a saving of 10 per cent. It is not stated in the paper that 10 per cent in weight can be saved in this manner, and, as a matter of fact, in constructing the trailer car there is no difficulty in saving considerably more than 10 per cent by the methods indicated.

In replying to Mr. Carter, I should like to say that I am much obliged to him for drawing attention to that point about the resistance of the motors. The curve is not obtained by means of readings of the speed, but from the readings of a pendulum in the dynamometer car, which gives the total actual resistance of the train in a very much more correct way than it can be obtained by the speed readings. It is the total resistance, so that if he is correct in his figure of 4 lb. per ton for the resistances, which might properly be attributed to the motor itself, and which are absorbed in the motor when running, that would bring that curve down to a figure which approaches the curves with which we are more familiar.

Several speakers seem to think that it was suggested in the paper that the strength of the car should be diminished as the weight was diminished, but that is not the intention. As Mr. Carter pointed out, I thought we ought to save unnecessary weight, and that where we could use stronger and lighter materials without any sacrifice of strength, that should be done, but that it did not seem to have been carried out. Mr. O'Brien.

Coaches have very generally up to the present time been built of mild steel, or mild steel and wood, and little attention has been paid to the importance of closely investigating the possibility of reducing their weight. It can be conclusively shown that to introduce unnecessary weight is to throw money away in perpetuity; and I should like again to emphasize the fact that the body which carries the passengers is the most important part to consider from the point of view of weight-saving. But the weight of the body reacts throughout the whole equipment. A light body and underframe means light bogies to carry them: light bogies mean light motors: light motors again mean that the electrical equipment which has to be carried on the body will be light, which again in its turn permits of a slightly lighter body. Our knowledge of the strength of materials has greatly advanced in the last 10 or 15 years, and it is most important that we should turn that knowledge into advantage in connection with rolling stock construction.

Mr. Bowden notes that in the bogies the journals are without button heads: this arrangement has proved very satisfactory in practice. The gear wheel is not split because the solid wheel is both cheaper and stronger. The average life of the gears on the Liverpool–Southport line is over 250,000 miles, and consequently it is not worth while making a special arrangement for renewal purposes.

In answer to Mr. Burgess, the "wheelbarrow" method of suspension has survived as being the simplest and cheapest. As to ventilation, I agree that a downward movement of the air produces the most sanitary results, but it is a very difficult system of ventilation to carry out in a railway carriage. The system described produces fairly good results.

Where a bulk supply of current can be purchased cheaply I agree with Mr. Baker that it is far better for a railway to purchase its electrical energy. On the North-East Coast waste-heat stations and a varied load with a magnificent diversity factor make it possible to supply energy so cheaply that no municipality or railway company could hope to do the same. Elsewhere, however, small stations with a poor diversity factor are universal, and while this is so railway companies do well to build their own generating stations; for a railway load has an excellent diversity factor of its own, and the magnitude of the load is such—on a successful scheme it will seldom be less than 20 million units per annum—that the standing charges per unit will be less than in the case of municipal stations which are notable for their extravagance in buildings and plant. The changes in policy which occur in municipal stations are partly due to the fact that the latter are controlled by political parties and partly to the fact that the poor salaries paid by the corporations cause perpetual changes in the staff. Liverpool, Manchester, Newcastle, and the London County Council are all cases in point.

The directorate and chief mechanical engineer of a railway company change infrequently, and the policy is continuous. The problems connected with the generation of electricity are mainly mechanical; the chief mechanical engineer is usually a man of broad views and wide experience, and in the ordinary operation of his department he has the assistance of experts in each particular branch—electricity, marine engineering, cranes, stationary boiler plant, etc. He is therefore eminently fitted to deal with the problems of a power station. The railway will already possess a staff for dealing with coal analyses and purchase properties of oils, and water, etc., and for testing purposes, and hence a generating station can be operated with an economy unknown among municipalities or in most companies. I do not dispute Mr. Baker's contention that the 50 generating stations in London are wasteful and that it is a problem to know what to do with them; on the contrary, I am pleased that he should have adduced this argument to prove the wisdom of the policy adopted by the London & North-Western and London & South-Western Railways. It is of course a matter for regret that there is not a central supply authority for the whole of London; as soon as such an authority is in being no doubt the railway companies will be in no two minds about purchasing their current. I should like to say further in answer to Mr. Baker that in my opinion in order to get the best results in a very large organization like a railway company it is essential that the whole of the mechanical engineering and transport problems should be grouped under one authority. Many hard things have been said recently about the Great Eastern Railway, but the Company has shown very great wisdom in appointing an engineer as general manager, who will be able to co-ordinate the various mechanical problems now divided between departments. Mr. O Brien.

DISCUSSION ON

"SOME RAILWAY CONDITIONS GOVERNING ELECTRIFICATION." *

SCOTTISH LOCAL SECTION, 17TH FEBRUARY, 1914.

Mr. W. W. LACKIE: The main point in this paper about which I wish to speak is the statement that the electric tramways compete directly with the railway services in many large towns, and that railway companies have been obliged to reduce their fares owing to tramway competition. I thought it was quite agreed that a tramway is a distinct benefit to a railway, in so far as the tramway acts as a feeder to the railway and increases its traffic. It is true that the tramway undertaking uses the streets, but it also bears the cost of paving in a very substantial manner, viz. to the extent of two-thirds of the area of those streets, an expense that would otherwise fall upon the rates. The tramway department further pays rates on the full value of its permanent way, whereas the railway companies only pay rates on one-third of the value of their permanent way. The extension of tramway lines to suburban areas has had the effect of stimulating the building trades in those areas, and of developing a residential population, both of which results undoubtedly react beneficially on both goods and passenger railway traffic. It has been shown on the railways in several districts that the traffic has increased when the tramways have been extended. The motor omnibus acts similarly in favour of the railway. The author indicates in the paper that what is wanted in suburban traffic on electric lines is either an increase in the fares or the ability to purchase electrical energy at ¼d. per kilowatt-hour. It seems to me that the running of a railway is very much like the operation of an electricity supply undertaking, inasmuch as standing charges are an important feature in both. In my opinion, instead of being increased, the fares should be reduced. Our experience in Glasgow is now well known. Instead of carrying a passenger half a mile for ½d., the Corporation increased the distance to 1 miles for ½d. The increase in revenue from this cheaper fare has more than covered the cost of the reduction. Would it not pay the railway companies to reduce the first-class fares and so increase the number of persons who travel first-class? In the case of the Glasgow Electricity Department, which showed a deficit of £4,000 on one year's working, the tariffs were reduced and the deficit was turned into a surplus in the following year. The author states that cheap coal is a hindrance to the electrification of the railways; but the price of coal in America, where electrification has been adopted, was only half the price of coal in this country. It is stated that the difference between the heat value of the coal in the bunkers and the work done at the draw-bar of the electric locomotive is only 6 per cent. I do not see why this should not be 12 or even 15 per cent. It may be of interest to recall that in February, 1909, I read a short paper * before this Local Section in which I gave an account of an experimental electric locomotive which was run between Glasgow and Edinburgh as early as 1837. Mr. Lackie.

Mr. C. E. COCKBURN: Whilst I am in favour of electricity as a motive force, I do not think the time is yet ripe for its introduction for long-distance traffic. There is a considerable difference between the working of electric tramways and underground electric railways in London and the operation of the steam-worked overhead railways. With regard to the difficulty of handling long-distance and short-distance traffic in the limited area inside big terminal stations such as those in Glasgow and London, I consider it to be better for the railway companies to leave the local traffic in short-distance areas to the electric tramways, and to concentrate their attention on the long-distance traffic, which can be more successfully dealt with for the present by steam railways. As an example of the difficulty of handling traffic to places on the Clyde, in the case of a steamer capable of carrying 1,000 or 1,500 people, with the Mr. Cockburn.

* Paper by Mr. Roger T. Smith (see pp. 293 and 368).

* W. W. LACKIE. Early experiments in electric traction. *Journal I.E.E.*, vol. 42, p. 626, 1909.

present electric rolling stock three or four trains would be required to convey a boat-load of passengers; with long block sections this would result in the passengers being kept waiting too long between the arrival of the first and last trains to permit of such a system being feasible, when by a competitive route which had steam-hauled trains an equal number of passengers would have been conveyed perhaps in one or at most two trains. Consequently, it is impossible at present to contemplate the introduction of electric traction to handle such traffic as this. In justification of my views I would call attention to the fact that on busy days when such events as football matches take place in Glasgow and the crowds have to reach a given point by a given time, the tramways are unable to meet the whole of the requirements, as they cannot provide a sufficient number of cars to carry the public when the latter present themselves in a body; neither can the public be induced to travel during a longer period in order to suit the system of car working. The public therefore have to fall back on the railways at the last moment in order to be carried to the match before the game commences. I am therefore convinced that until heavier loads can be carried it would be unwise for the railways to contemplate the introduction of electric traction as their only means of haulage. I am a great believer in electric power, which can be made use of on a railway not only for haulage but for lighting, signalling, block working, and the manipulation of points, in a way which was impossible with any other form of power. In fact, I consider electricity will naturally be the power of the future; but until it can be produced more cheaply I am of opinion that the moment has not yet arrived for its introduction on railways, where it is really wanted more for handling long-distance than short-distance traffic, inasmuch as the latter is competitive with the tramways, which are able perfectly well to handle this traffic. The railways would not be compelled to reconstruct their big terminal stations if this short-distance traffic were dealt with by the tramways as at present, the existing railway stations being large enough in most cases to handle the long-distance traffic without any further additions.

Mr. J. M. Scott Maxwell: I think the author's introduction is an admission that all is not as it should be in this country with regard to the question of railway electrification. He says that it is much easier to change "things" than to change the habits of large bodies of men; but surely in order to change a single thing some man has to be changed in some way or other. Is it not a much greater task to change the attitude of parliament, government departments, railway directors, and general opinion, than it is to change the daily routine of railway operatives? I have always thought that the engineering profession is very greatly to blame for the present lack of progress, because they ought to seize every possible opportunity that will enable them to make a little headway against the inherent conservatism of the travelling public and more especially of railway directors; but this they have not done. I spent some years in the United States just at the start of heavy electric traction, and I had considerable experience of the electrification of the New York Central Railroad. Since then I have endeavoured to follow the American developments as closely as possible, and these developments are worthy of full consideration by British engineers. Many American engineers have had to repeat over and over again to some of the very enthusiastic advocates of electric traction that the first big schemes were not due to the proved economy of electrical working in comparison with steam working. Public opinion, expressed through the authority of the City of New York, compelled the New York Central Railroad to abandon steam locomotives owing to the danger arising from the smoke in the tunnel entrance to their New York terminal. The New York, New Haven & Hartford Railroad, using the same terminal, came under the same condemnation. The American engineers were sharp enough to seize that opportunity as a start and are now pressing forward electrification in a thoroughly business-like fashion. How about the engineers in this country? Six years ago I read a paper on the "Problem of Heavy Electric Traction" before the Iron and Steel Institute of Scotland. Before reading it a newspaper reporter asked me for a synopsis of it. I pointed out to him the disgraceful condition of the underground sections of the Caledonian and North British Railways in Glasgow and, as Mr. Roger Smith has said in relation to underground railways in general, I told him they ought to be electrified. I told him what New York City had done and what other American cities were doing, and pointed out that the Glasgow Corporation did nothing, the only reason which I could discover being the fact that such electrification would reduce the revenue of the Corporation tramways and increase the railway revenue. Six more years have passed and these underground sections are still tolerated by an unenlightened and apparently helpless and apathetic public.

Turning to the financial factors, Mr. Smith says that directors can only be expected to spend money which will help to increase the revenue. That is a sound argument; but at the same time it is difficult to see, for example, how the heavy expenses incurred by the Caledonian Railway Company at the Central Station (Glasgow) can increase the profits. Perhaps the profits were not expected to increase, but the expenditure was nevertheless considered necessary. This proves that railway directors are willing to spend money in such orthodox ways as building a bridge and a station, but that expenditure on electrification, even though it may greatly increase terminal facilities, leaves them indifferent or lacking in courage. We all know that the Board of Trade standards are in many cases only impeding progress. Electrical engineers are almost justified in thinking that steam engineers are responsible for the creation and maintenance of these excessively severe standards. The longer they exist the longer will steam traction manage to survive. It is for the electrical profession to educate the government and the people to a better sense of proportion. As for the difficulty of dear money, it is likely to get cheaper, temporarily at least, in the future, and is it not cheaper here than in any other country? As for higher labour costs, wages have risen considerably in America, but the American government are not inclined to allow the railroad companies to raise freight charges or passenger fares. Such contemplated increases seem regrettable in this country, where freights are already so abnormally high.

Turning to some of the engineering factors, American engineers seem to have reached the decision that railways should no longer generate their own electric power, but

should purchase it from power companies. This has been the evolution of electric power in the industrial world, and it seems natural that it should also apply to railways and especially to the electrification of terminals in large cities. This does away with the greatest part of the new capital expenditure and should do much to lessen the fears of the directors. Surely there is enough enterprise in London, for example, to raise money for generating electric power to supply all the London railways within, say, a 30-mile radius. By giving power companies a right of way along the railways further economy could be effected. While we are obliged to accept the small headway and clearances on all British railways as a serious handicap which even the future will probably never remove, it seems all the more essential that we should have stronger and not weaker draw-gear than on American railways so that we may have still longer trains. When the long overdue question of automatic couplings and automatic brakes is finally faced, it is to be hoped that electrical engineers will see that the draw-gear is then made amply strong enough for the future possibilities of electric haulage.

While this paper does not raise the still very vexed question of systems, it is, I take it, an introduction to later papers in which this point will be discussed, and a few words as to American tendencies may therefore be of interest. Mr. Smith seems to think that the single-phase system is at present the most promising because of the possibility of using different running speeds. Now, some American engineers very strongly condemn the adoption of the single-phase system as being the greatest cause of the slow development of heavy electric traction. They claim that the cost of operation and upkeep is very much higher and that many single-phase systems are being replaced by continuous-current systems at 2,400 volts. Such systems are really the same as the older 600-volt system except for insulation, and there is every reason to expect the voltage to rise, as indeed has been decided upon in this country. This claim is not only applicable to interurban railways but also to the heavy electric traction on the main railroads. The advocates of the single-phase system have still to solve economically the serious trouble experienced in telephone and telegraph circuits which are in close proximity to the heavy current of a single-phase trolley system. There are other engineers and other interests who strongly defend the single-phase system. The controversy, I am afraid, has been rather bitter at times, but it looks as if the advocates of continuous current will win. This will mean three-phase transmission to rotary-converter sub-stations. Here economies may be effected in the future by the substitution of mercury arc rectifiers in place of rotary converters; but, so far as I know, this is not a commercial fact as yet, although I believe I have reliable information that it may be in the near future. The American tendency in locomotive design is to build 100-ton locomotives with four motors direct on the axles for high-speed passenger service. These locomotives are used singly or in pairs, and have usually three running speeds—series, series-parallel, and parallel. The author does not think that electric locomotives with series motor characteristics can do what certain types of steam locomotives can easily accomplish in this country. Is it not possible that with electrification it will be easier to maintain schedule time? The electric locomotive can stand adverse weather conditions better and is not subject to the drawbacks of poor coal and tired firemen. When we tested the large continuous-current locomotives for the New York Central Railroad along a part of their main-line system between New York and Buffalo, we used at times to race the fastest steam trains in America. With a 300-ton train we could run up to over 80 miles an hour. This we accomplished with the greatest ease, because the man in the sub-station would see the situation and boost up the voltage. I only relate this as an interesting possibility of getting over the trouble of the series characteristics. If a train in a certain sub-station section got badly behind time, the voltage could be raised, perhaps by the exact amount, so as to ensure the train making up the time; and if other trains on the same section got ahead of time they could slow down. Mr. Maxwell.

With the possible exception of Ireland, Glasgow is the most retrograde part of the United Kingdom in respect of electric railways. We have a large local population but not a single mile of electric railway in the district or anywhere in Scotland. Nevertheless, I believe that in spite of the general pessimism there is a suitable field in the Glasgow district, and any sign of such development would in all probability attract some of the great initiative and enterprise which is so conspicuous in our shipbuilding industry and so lacking in our railways.

Mr. S. Mavor: I should be glad if the author would give in his reply a definition of the term "load gauge." The context does not seem to explain the term quite clearly. I should also like to ask him how the draw-bar pull in long trains is affected as the train passes round curves, and whether in the case of a long goods train driven electrically he would suggest, instead of one powerful leading locomotive, the use of two or more locomotives distributed along the train and controlled from the leading locomotive. I think, as the author says, that cheap coal in this country is one of the factors hostile to railway electrification; but he may take encouragement from the certainty that coal will in future be dearer. In attacking a problem of this kind electrical engineers have the great advantage, which supports them in attacking nearly every other problem of the kind, of possessing facilities for the exact measurement of power. This enables them to deal with problems with greater precision of method, and it has enabled them, as the author has pointed out, to state definitely the prospective costs under any given conditions. Mr. Mavor.

Mr. J. A. Robertson: It would be very interesting if the author would give further details showing how the relative costs of $7\frac{1}{2}$d. for electric locomotives and $10\frac{1}{2}$d. for steam locomotives have been determined; it is stated that the difference would not be sufficient to pay the standing charges on the cost of electrical equipment, a statement which is probably true with existing conditions. For comparison with these figures, I find that Mr. Vaughan in a discussion before the Canadian Society of Civil Engineers states the ascertained cost of steam working to be 20d. per train-mile, and of electric operation 12·5d., that is to say a difference of 37 per cent in favour of electricity, compared with Mr. Smith's 30 per cent. The overall efficiency of the electric system is given as 6 per cent; this seems very low, and I should like to ask the author to give the relative proportion of losses in the power station and in the transmission line and locomotives. A Mr. Robertson.

Mr. Robertson. power station efficiency of 16 per cent should be attainable with the load factor from a railway system; and one generating station at least in this country claims at present to be obtaining an overall efficiency of $18\frac{1}{2}$ per cent. It would therefore appear that there is a very great loss between the power station and the energy delivered at the axles of the locomotive. I also think that the author is too pessimistic about the design of electric locomotives, and that English designers will have no difficulty in providing him with an electric locomotive capable of developing 1,200 h.p. at 70 miles per hour. I agree with Mr. Lackie that the railway companies have themselves largely to blame for being unable to face the expense of electrification. There has been too much overlapping and unnecessary competition in the past, and if the railways were organized under one authority they would be in a better position to face electrification than under present conditions. Take the route from London to Manchester, for example. Here there are three competing railways running trains at intervals of two to three hours. None of the companies are in a position to electrify, but if the whole of the fast traffic from London to Manchester were dealt with on one line, the increased traffic density would in all probability justify the expenditure. The problem should really be considered with a view to future requirements rather than to existing conditions. If the inhabitants of London make six times as many journeys by rail or tram now as they did ten years ago, surely it is not too much to expect that with better facilities a large increase may also be looked for in long-distance traffic. I understand that the increase of traffic on the electrified portion of the London, Brighton, & South Coast Railway has been so great that the Directors propose to electrify the line right through to Brighton.

Mr. Smith. Mr. R. T. SMITH (*in reply*): Mr. Lackie referred to the competition of electric tramways with railways as a blessing to the railways, and this view was dealt with at some length by Mr. Cockburn. It may be a blessing in disguise, and I agree that that railway is on the whole the happiest which, like my own company the Great Western Railway, has comparatively little suburban traffic. Mr. Lackie compared a reduction in railway fares to secure more traffic as equivalent to a reduction in the price of electricity in order to increase its sale, or of reduction in tramway fares. Although the increase to the traffic would add greatly to the peak load, that may be satisfactory if the railway is not already congested; but if accommodation is hampered by non-paying traffic, a considerable chance is run of injuring the paying traffic.

Mr. Cockburn dealt with the difficulties of suburban traffic and tramway competition in a most refreshing manner. I did not quite follow him, however, as to the difficulty which he suggested occurs in moving large crowds by electric traction. As an example, take the race traffic to Aintree on the Lancashire & Yorkshire Railway's Southport electric service. Each 60-ft. coach seats 90 or 100 passengers, and half the 1,500 passengers can be taken in one 8-coach multiple unit train. It is agreed that the underground railways of London are like glorified tramways, but some sections run out for long distances into the outer suburbs, and on the busiest sections 44 trains each way are being run per hour. Nothing like that can be done by steam where station stops are of the order of half a mile apart. I am heartily in sympathy with Mr. Cockburn's view that it is an advantage to do everything on a railway—traction, signalling, point moving, power, lighting, etc.—electrically. Mr. Smith.

Mr. Maxwell pointed out that the bulk of the railway electrification in the United States was carried out—for its tunnels and terminals—as the result of the pressure of public opinion and not from any ideas of economy. He also referred to the substitution on certain lines of continuous-current equipment for single-phase equipment where the latter had been installed. I believe that I am right in saying that this has occurred on street and interurban railways, and not on what Americans call railroads, which correspond to our railways. The railway is mostly run, as in our tramways, by means of single cars, and this shows the single-phase system at its very worst. A long and heavy train shows the single-phase system at its best and that may in part account for the way in which single-phase electrification is going ahead on the Continent of Europe, where main lines rather than terminals are being electrified. Mr. Maxwell's comparisons between what is being done in the way of electrification in the United States and over here is interesting and stimulating, but needs no comment from the author except to recommend it to the careful consideration of everybody.

Replying to Mr. Mavor's questions, the influence of curves in increasing the draw-bar pull is most difficult to measure with the dynamometer car, and the results given do not agree very well. A train is generally out of the curve before the effect due to the latter on the train ceases to be neutralized by the effect due to the curve on the engine. Mr. Mavor also inquired as to load gauge. The load, or loading, gauge may be defined as a profile within which every vertical section through the rolling stock—whether locomotive or carriage or wagon—must be contained. No portion of the side, top, or under surface of a coach or locomotive, or of the load carried on a wagon, must be outside this profile. The load gauge fits inside the minimum structure gauge with several inches' clearance, this clearance varying on different railways. The small size of the structure gauge on British railways is a great difficulty in electrification with overhead conductors where the current collectors must violate the rule and be outside the load gauge in order to touch the conductor which is inside the structure gauge. The available space between the two gauges is often quite inadequate for overhead construction. Mr. Mavor asked whether a train was best hauled by one or two electric locomotives. The matter is one for experiment. It may be preferable to keep down the number of types of locomotive and double bank them for heavy trains. This is the method proposed for working the electrified circular railway in Berlin, the two locomotives (one at each end of the train) being controlled from either end. With the cost of electric locomotives as high as it is at present I think single locomotive units will chiefly be used. Mr. Mavor also referred to the cheap and easy measurement of electrical quantities. There is no doubt that if measurements with the steam locomotive were not so difficult it would have advanced more quickly than it has to its present state of development. The steam locomotive is still being improved, and

Mr. Smith. superheating has been stated recently to be the greatest improvement in the last 30 years.

Mr. Robertson, referring to the comparative annual costs of an electric and steam locomotive, asked what efficiency had been assumed between the heat in the coal and electrical energy delivered to the outgoing cables, stating that efficiencies as high as 18½ per cent had been obtained. Mr. Robertson does not state if that is the overall annual efficiency or the maximum. For the efficiency of 6 per cent stated in the paper between coal in the generating station and draw-bar pull, an annual heat efficiency in the generating station of 11 per cent was assumed, as this was the highest annual efficiency that the author had seen stated for any generating station connected with railway work. The efficiency of the locomotive, between the current collection and the draw-bar, was taken (for fast service and few stops) as 73 per cent. The efficiency of the sub-stations as 79 per cent. The efficiency of the transmission line to the sub-stations was taken as 95 per cent, and from sub-stations to train as 93 per cent. The efficiency between the coal and the supply to feeders, averaged over the year, was 11 per cent. As to railway electrification under present conditions, I am entirely in agreement with Mr. Robertson's clear statement of the case, that its economy or otherwise is dependent on the density of traffic. He pointed out that it was the fault of the railways in their early days that the density was now so low, owing to unnecessary lines having been built for competitive reasons; but Parliament, which has always insisted on competition, must take its full share of the blame. In the treatment of passenger traffic costs a low density was taken in the paper, and the form of analysis permits of any increase in density being taken account of. It is when the density has increased to such an extent that steam working has come to the end of its tether that there is no question about electrification being the proper thing, as it adds to the capacity of the existing permanent way and stations.

Manchester Local Section, 24th February, 1914.

Dr. Rosenberg. Dr. E. Rosenberg: In order to introduce electric traction on railways it has first to be shown, according to the author, that the electric locomotive will do what the steam locomotive does. Perhaps the author did not wish to give too optimistic a view of the situation by showing that electric traction can achieve results which the steam train cannot achieve. When he states that no electric locomotive has yet been built which can give 1,100 h.p. at 70 miles per hour, if it were designed for hauling only such maximum loads as obtain on British railways, he is of course right. The statement must not, however, be understood to mean that there are still very difficult problems to be solved in order to comply with such conditions. I am convinced that if any railway company were to ask for tenders for an electric locomotive to comply with such a specification they would receive reliable quotations from every responsible manufacturer. There are no new fundamental problems to be solved in this respect. So far back as 1903 the problem was solved of running electric trains at 130 miles per hour. At that time it was thought that electric traction would mean a fast service, and demonstrations were made on an ordinary steam line which was adapted for electric service to run electric cars between steam traffic at a speed of over 200 kilometres per hour. At that time it was thought that only motors without commutators could be relied upon to run such a service, and the experiment was made with three-phase current. I do not believe, however, that anybody would now hesitate to run absolutely the same service with commutator motors, whether of the single-phase or continuous-current type. We now have 50 ∿ rotary converters which have a normal commutator speed of 60 miles per hour. The author has referred to the capacity of the steam locomotive to give constant output at various speeds. It is, of course, true of the plain series motor that there is only one speed for a given load and a given voltage, but the shunting of the series field has been developed during the past few years, and on the large Pennsylvania locomotives such shunting is used with excellent results, 50 per cent of the armature current being shunted from the field coils. For starting and accelerating an extra strong field is provided, but after reaching a certain speed a normal field is used. On the Pennsylvania locomotives the shunting is done in a single step. The motors have commutating poles; the commutating conditions are excellent, even with the normal field, and not the slightest difficulty is experienced. If instead of one step the shunting is effected in two or three steps, several economical speeds can be obtained for the same work. The author mentioned the possibility of using separate excitation. This is an extremely interesting problem. It was suggested that for ordinary tramway service a compound motor should be used instead of a series motor. I am afraid that it would not be practicable to use an ordinary separately excited motor, and that every endeavour to get such a speed regulation would have to be in the direction of compound excitation, for the extremely good qualities of the series motor should not be abandoned entirely. We may possibly assist it by means of a shunt winding, or by sending through the series winding current from another source, or by using a kind of booster in parallel with the series winding. With regard to the traffic conditions that allow of electrification, the author rightly mentioned that it is first of all a financial problem to find out whether the additional traffic to be obtained will give a reasonable return. Those who have to solve this problem must, however, have some imagination, because if they want first to see on paper proof that every penny spent will be refunded, I am afraid it would be an impossible problem. It is strange that one of the most promising suburban lines in the Manchester district is still operated by steam locomotives, although we have heard during the past ten years that it was to be electrified. I am sure that no line would lend itself better to electrification, having a length of only 9 miles and a large passenger service, and it is very disappointing to hear that the railway authorities have again abandoned the project. I understand that in order to determine whether the electrification would pay, inspectors were sent to count the tramway passengers on the competing lines; and it was eventually decided that electrification would not pay even if all the tramway pas-

sengers could be marshalled into the electric trains. I wonder what the result would have been if, before building the first railway from London to Manchester, inspectors had been sent out on to the roadway to count the number of travellers.

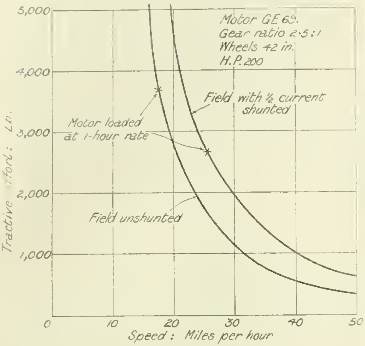
Mr. E. ROTHWELL: I was particularly interested in the point that the author raises that if the cost of electrical energy cannot be reduced to $\frac{1}{8}$d. or $\frac{1}{4}$d. per unit, electric traction on railways will not come to the front, and it seems to me that if we have to depend on current being sold at $\frac{1}{8}$d. per unit there is not very much hope for electric traction on railways. The author mentions the shunting engine. At the present time we do not find steam shunting engines undertaking the work that the better engines are built to take, and it would only be a matter of the electric shunting engine being designed for that particular class of work, and special engines for the heavier traffic. The author suggests that the generation of electrical energy is a trade in itself, and he thinks that it would be better if the railway companies bought the current which they require. I differ from him there, as I think the railway companies know their own conditions best, and are in a better position to deal with the different problems that will arise. With regard to the method of operating electric railways, I certainly think that if there are to be electric railways in the future we shall have conditions growing up to cope with the same. If all our railways were, for instance, at present electrified on the overhead single-phase system, there would be a scarcity of men to operate them, as the men would all be too busy looking after the line.

Professor E. W. MARCHANT: There are several facts in the paper which I think are very interesting. The first is that the largest suburban service is that from the St. Lazare Station in Paris. I was one of those who regarded the railway systems in France as very much behind those of England, and it is therefore surprising that the largest service should be from one of the Paris stations. With regard to the future of the electrification of railways, a line showing very clearly what may happen in developing traffic is that of the Mersey Railway Company. When the line was working under steam the number of passengers carried was just over 5,500,000 per annum, whereas after 10 years' electrification the number has increased to 13,240,000 per annum, excluding season ticket holders, and is not stationary at that figure. The cleanliness and comfort of electric trains compared with steam trains are to my mind two of the strongest arguments in favour of their use. It is my misfortune to have my laboratory near to a half-open tunnel on the London & North-Western Railway, and the amount of dirt and dust we get from it is evidence of the accuracy of the statement made by the Chicago city smoke inspector that 43 per cent of the total smoke and over one-half of the total dirt that collects in such a town as Chicago come from the railway locomotives. It may be of interest to record some results that we have obtained in tests made with the Wimperis accelerometer as to the actual rates of acceleration and deceleration on some of our electric railways. Tests made on the North-Eastern Railway of the actual acceleration at starting give 1·5 ft. per sec. per sec., afterwards falling to a steady value of 1 ft. per sec. per sec. until the period of acceleration is nearly over. The braking effort observed on one train was 300 lb. per ton, while in another case, when the train was pulled up very quickly, the braking effort rose to 350 lb. per ton, which is the greatest value observed. On the Liverpool–Southport line of the Lancashire & Yorkshire Railway, where we have also made some tests, the maximum acceleration is 2 ft. per sec. per sec. The normal initial acceleration is usually 1·3 to 1·5 ft. per sec. per sec., after which the acceleration gradually diminishes to about 0·5 ft. per sec. per sec., again rising to 1·5 ft. per sec. per sec. as the train gets up to full speed, presumably when the controller is moved over to the parallel notch. The maximum deceleration is about 250 lb. per ton, corresponding to 3·2 ft. per sec. per sec. The last railway on which we made tests was the Liverpool Overhead Railway; and this line is interesting because it gave the largest acceleration which we observed. The maximum acceleration with the present service is 2·7 ft. per sec. per sec. At one time motors were installed which gave an acceleration of 4 ft. per sec. per sec. This acceleration gradually falls to 1·5 ft. per sec. per sec. As far as braking goes, the maximum effort for braking is 300 lb. per ton, corresponding to a deceleration of about 4 ft. per sec. per sec., the normal braking effort being about 200 lb. per ton.

Mr. J. L. MOFFET: I think electrical engineers cannot insist too strongly or too often that comparisons between electric and steam traction can only be made when the two services are working under the same conditions. Usually when a line is electrified the schedule is very much increased and then comparisons are made between running costs under the old system and the new. As is only to be expected, the costs after electrification are at times higher than they were before, although, if the new installation had been designed for the same schedule as with steam working, the costs would have been considerably reduced. The working cost increases as the square (or higher value) of the schedule speed, and where the speed has been increased it is because the management has decided that the advantages accruing will more than pay for the extra expenditure. Mr. Aspinall in his presidential address to the Institution of Mechanical Engineers in 1909,* illustrated the effect of an increase in speed. He showed that on the Liverpool–Southport line, during the transition period while the steam trains were sandwiched with the electric trains, the steam trains were speeded up with the result that the coal consumption reached the high figure of 100 lb. per train-mile. A usual figure with normal speeds is 50 to 60 lb. per train-mile. I should be interested to hear what density of traffic the author considers necessary in order that the savings effected by electrification may give a reasonable return on the extra capital expenditure. I recently worked out the cost for operating electric trains under steam conditions, taking as a typical case a 100-ton train (exclusive of the locomotive portion) running at an average speed of 25 miles per hour with a stop every $1\frac{1}{2}$ miles, and found that the saving would pay 8 per cent interest and depreciation on the extra capital expenditure when the density of traffic reached an average of $1\frac{1}{4}$ trains per hour. On page 302 Mr. Smith claims as an advantage of electric traction that "any driver can work any locomotive, which is not the practice in this country with steam locomotives." I think that on some railways in this country drivers are now changed from one engine to another, although passenger

* *Institution of Mechanical Engineers, Proceedings*, p. 423, 1909.

drivers will be kept as far as possible to passenger engines in order to ensure safety, this grade only consisting of tried men who have proved themselves reliable on other classes of traffic. Dr. Rosenberg points out that by shunting the field of a series motor a higher running speed can be obtained; I think, however, the same variation cannot be obtained in this way that could be obtained by weakening the field of a shunt motor. This can be seen from the accompanying diagram for a G.E. 69 motor, which shows



that supposing the necessary tractive effort be constant at 3,000 lb. the speed will only be increased from 20 miles per hour to 24 miles per hour by shunting half the field current; whereas if the motor had been shunt wound so as to have the same strength of field as the series motor at 20 miles per hour, then reducing the field current to one-half would increase the speed to 30 miles per hour. Dr. Rosenberg also mentions that electrical engineers could now build a locomotive that could give the draw-bar pull stipulated by Mr. Lydall, viz. $3\frac{1}{2}$ tons at 75 miles per hour. I think the real difficulty is to obtain a locomotive that will give this large power at a high speed and also give this or a smaller power at any lower speed. As the author indicates, the steam locomotive is a very flexible machine. Any desired load can be hauled at any speed, within the power of the engine, and also very large overloads can be obtained at any speed (at the expense of efficiency) by working with a late cut-off and forcing the boiler. One speaker stated that he did not think there was any prospect of obtaining electrical energy at $\frac{1}{8}$d. per unit, but Mr Wollaston at a recent meeting of the Chemical Society showed that by using a fairly good quality of peat with recovery gas-plant, not only could power be obtained for nothing, but that a clear profit of 21 per cent per annum on the capital expenditure could also be obtained.

Mr. R. T. SMITH (*in reply*): Dr. Rosenberg stated that little reference had been made in the paper to the things which the electric locomotive can do but which the steam locomotive cannot do. The North-Eastern Railway Company's electrification of their Shildon and Newport mineral line, referred to in the paper as now in progress, is a very good example. There is a heavy mineral traffic downhill to the Middlesbrough district, and the steam locomotive which now takes the full trains down can only take half the empties up. The electric locomotives that I saw to-day in various stages in the railway company's workshops at Darlington will be able to take full trains of empties up the steepest gradients and greatly increase the capacity of the line. Dr. Rosenberg very properly referred to the high speeds that were obtained in the Zossen experiments, and instanced the Pennsylvania locomotives, where the series fields are shunted by a diverter for the higher speeds. The actual result of this in tractive effort at the wheel rims and in speed is shown for one of the Pennsylvania locomotives in Fig. 2 of the paper. It is surprising that this method has not been more used with continuous-current locomotives. It will be satisfactory to railway men if designers of Dr. Rosenberg's calibre will take up the question of improving the characteristic of the continuous-current series motor in one or other of the ways that he suggested. For the North-Eastern Railway locomotives referred to above there are 20 control notches, and I believe only 2 of them are running speeds; this is not satisfactory. Dr. Rosenberg also referred to the need of imagination in railway men. Railway men have often been alarmed by the wealth of imagination in electrical engineers, and an average between the two should be struck over the railway electrification business. As far as the paper goes I have endeavoured to confine myself to present conditions only. When it is remembered that one of the best engineered and managed concerns in the world—the London tubes—only pays about 1 per cent on its stock, it is not to be wondered at that railways hesitate to spend capital on such lines as the Manchester–Altrincham, referred to by Dr. Rosenberg, with a maximum of 6 or 7 trains each way per hour instead of the 40 per hour on the London underground railways.

Mr. Rothwell did not agree that it was best for a railway to buy its electricity, and stated that if electrification depended on a price of $\frac{1}{8}$d. per unit there was little hope for it; but it must be remembered that price applies to fast passenger service only. He suggested that if a railway were entirely equipped with overhead conductors the time of the whole staff would be taken up in maintaining it. No railway man would have overhead equipment if it could be avoided, but the advantages may be more than worth the disadvantages.

Professor Marchant was surprised to learn that the St. Lazare station in Paris had a bigger suburban movement than any other European station; but the figures prove it. It is fortunate that he mentioned the Mersey Railway, for it is probably the best example in this country of electrification, resulting in the turning of a financial failure into a financial success by doing what steam could not do. The paper* that was read before the Institution of Civil Engineers in November, 1909, by Mr. Shaw, the engineer of that line, gives the most complete comparison between steam and electric working that has ever been published. It must be remembered that the physical conditions of the Mersey

* J. SHAW. The equipment and working-results of the Mersey Railway under steam and electric traction. *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 179, p. 19, 1909–10.

Mr Smith.

Railway favour electricity and handicap steam; but its success should be studied by all interested in the question. Professor Marchant further referred to the cleanliness of electricity—which I find is much appreciated on the Tyne—and instanced the terminal electrifications in the United States forced on the railways by public opinion or the presence of long tunnels. Perhaps the same reasons may suggest terminal electrification in our own country; but the effect of the domestic hearth and the factory in blackening the air must in this country completely swamp the effect of the steam locomotive.

The acceleration and deceleration rates actually measured for suburban service in the North are most interesting. On the London urban and suburban electrified lines accelerations are mostly from 1·5 to 1·7 ft. per sec. per sec. with decelerations of rather more than double this rate.

In claiming that electric and steam services must be the same to be compared, Mr. Moffet instanced the high coal consumption of steam locomotives when drawing trains over the Liverpool-Southport line sandwiched between electric trains. The difficulty of steam measurements has I think limited the other measurements which might have been taken by steam locomotive engineers in the past. Especially the cost of quite a small increase in acceleration was not understood until the simple and continuous measurements possible with electricity showed it. I am glad Mr. Moffet has worked out the paying train density, which, with $1\frac{1}{2}$ miles between stops and 20 miles per hour average speed, he makes $1\frac{1}{4}$ trains per hour in order to pay with electricity. A rather higher figure was suggested by Mr. Sparks in the discussion in London, and whatever the constants assumed may be, I welcome the method of analysis, for I am sure it is the correct way of showing the economies of electrification. It would seem, however, that the more convenient unit is the number of trains per mile and not the number of trains per hour.

I agree that, as the price of coal increases, the cost of steam traction will increase relatively to the cost of electric traction, but steam locomotive engineering is not by any means standing still. Superheating effects a coal saving of from 15 per cent in well-designed locomotives to 25 per cent in badly designed locomotives using saturated steam, and if it is remembered that the locomotive coal bill of the London & North-Western Railway for last year was over one million pounds sterling, savings of that order have great importance. The chief object of the paper was to induce electrical engineers not to under-estimate the difficulties to be overcome.

Further Contributions to the Discussion.

Mr O'Brien.

Mr. H. E. O'Brien (*communicated*): As a railway and locomotive engineer who for some years had to operate one of the suburban electrifications referred to in the paper, I should like to congratulate the author on the most reasonable contribution yet made to the subject of railway electrification. The point made by him as to the long-distance fares having to make up for the far greater cost of the short-distance stopping service is very apt; it is too often forgotten that high speed means long-distance fares, because it extends the distance radius of the electrification and takes the electrification outside the competitive omnibus and tramway zone. As to the operation of fast passenger services by electric locomotives, the idea at present is visionary in this country: the adoption of high superheat for locomotives, the introduction of the four-cylinder balanced simple or compound engine, and the prevalence of wiser ideas in boiler design have placed the steam locomotive far ahead of the electric locomotive for some time to come. It is erroneous to suppose that under modern conditions there is any necessity for a passenger locomotive to stand idle during 75 per cent of its time: if it does, the blame must partly and primarily rest with the traffic department for providing unsuitable workings involving periods of idleness; and partly with the engineer who fails to provide mechanical coaling appliances and arrangements for rapid washing out of the boiler. The average mileage per engine even on a line with a large amount of shunting should not be less than 20,000 miles per annum; and on passenger services the mileage per annum obtainable from a steam and an electric locomotive would only differ by the difference in mileage due to the electric locomotive spending about six weeks less in general repairs than the steam locomotive. It is stated in the paper, with reference to goods services, that nearly one-third of the engines are away under repairs; if this is the case on any railway, it points to incredibly bad management. It is not difficult to conceive railways where every driver can work every locomotive; in fact, no modern railway should have locomotives which it is not possible for every driver to work. The inflexibility of the electric locomotive is not sufficiently emphasized by the author; Mr. Lydall's paper, to which he refers, is practically entirely devoted to emphasizing this fact. It is pointed out quite correctly on page 300 that after making the rather large assumption that electrical energy could be bought at $\frac{1}{3}$d per kw.-hour, the saving in coal, which is the only saving possible, would only represent capital charges equal to £2,100 per mile of route, whereas the cost per mile of route for any electrification would be at least double this figure. It is estimated that the cost of the electric locomotive will be reduced when there is sufficient demand for it, but it is not stated on what grounds this assumption is based. Frames, cab, wheels, axles, axle-boxes, brake-gear, and in some cases connecting rods, are all common to both types of locomotives, and are the cause of no inconsiderable portion of the maintenance. The assertion made in the paper therefore amounts to stating that 1,200 h.p. of electric motors, with the necessary cabling and control gear, will eventually be less expensive than a locomotive boiler, cylinders, and motion capable of doing similar work. The 4-cylinder superheater locomotives on the London & North-Western Railway are capable of exerting 1,200 h.p. continuously over long distances, and it will be an agreeable surprise to locomotive engineers to learn that four 300-h.p. continuous-capacity motors, with their necessary control gear, could be purchased for the same price as a boiler, cylinder, and motion of one of those engines. It is also not realized that a heavy repair to a large electric motor is quite as expensive as the repairs of a boiler of similar capacity. The question of the electrification of sidings has not been very

O'Brien fully considered, and it is a very serious matter, particularly on those railways which have such an amount of traffic as to render them specially suitable for electrification. In a particular instance the total miles of running line are 880, and the total sidings amount to 480 miles, or 54·54 per cent of the total mileage of the railway. The majority of the sidings are very infrequently used by engines, sometimes not more than two or three times a week, but it is necessary that every siding should be traversible by an electric vehicle if electrification of the whole line took place. To electrify all these sidings with overhead wires would involve an enormous and unremunerative capital expenditure, and probably it would be better to provide storage-battery locomotives at all groups of sidings where shunting is continuous.

There are on nearly every railway specialized services which could be profitably worked electrically, but—and the platitude cannot be repeated too often—each case must be carefully considered on its merits. It is probable that in certain cases these special cases will be sufficiently numerous eventually to warrant the conversion of the whole railway to electric traction.

The author has most commendably avoided any show of bias towards particular systems of electric traction, and it is to be hoped that this may help to dispel the idea that those who have advocated in our present state of knowledge continuous current for suburban traction in any way feel committed to it as a solution of other problems. In cases where one system is suitable for suburban and another for interurban or main-line traffic, each involving a different system of collecting the current for the trains, it is possible that it may be a commercial proposition to keep the motor vehicles each to their own system of collection, but to equip the line in the smaller area with both types of track distributor. It was probably considered superfluous to emphasize in the paper the extreme flexibility of modern electric supply, but I think it would have been advisable to do so for the benefit of many railway engineers who are not conversant with the ease and security with which current can now be generated, distributed, and converted to alternating or continuous current of any voltage. Some of these remarks do not strictly apply to railway conditions governing electrification, but they apply to the converse, which is so nearly related to the subject of the paper as to be a good excuse for apparent irrelevancy.

Brook. Mr. R. V. C. BROOK (*communicated*): In connection with the author's figure for the cost of energy, if the electric locomotive is to compete with the steam locomotive, in order to produce current at ⅜d. per unit exceedingly large power stations must be built, preferably at the pit's mouth, and they must have a very high load factor. I should like to know whether the author has considered the possibility of the railway companies combining together to lay down power stations in various areas to supply the whole of the current required by the lines running in those areas. As a compromise between steam and electric traction, can the author tell us anything about the turbo-electric locomotive on the Reid-Ramsay system. Is such a system where the locomotive carries its own generating plant likely to be more efficient and more economical than the present all-steam system? In considering the cost of steam locomotives as compared with electric locomotives, the author states that taking an average cost of the average steam passenger locomotive, the figure is £1,175 per annum for each steam locomotive, this sum including capital charges, maintenance, coal, wages, etc. The corresponding figure for an electric locomotive is given as £1,250 per annum. The figures seem to be rather in favour of the steam locomotive, whereas one would have imagined the electric figures do not take into account the extra mileage that the electric locomotive would be able to run on account of its requiring less attention in the repair shops or running sheds. If this is taken into consideration the electric locomotive should have a decided advantage over the steam locomotive. Mr. Brook

Mr. R. T. SMITH (*in reply*): It is gratifying to find that Mr. O'Brien, with his large experience of the fastest electric suburban service to be found anywhere, as well as of the high-tension continuous-current service between Bury and Holcombe Bridge, is on the whole in agreement with the principles which the paper endeavoured to lay down. As a locomotive engineer he points out that the recent advance in the design of the steam locomotive makes it now far more unlikely than it might have been some years ago that high-speed passenger services should be worked electrically. Mr Smith

There is considerable danger of being misunderstood in dealing with the time that a locomotive is idle, but Mr. O'Brien makes out a worse case than the author, since he gives his locomotive only 20,000 miles per annum, while in the paper it is given as 27,000. Now 20,000 miles at an average of only 20 miles per hour is 1,000 hours per annum in service out of 8,760, or 89 per cent of its time idle; but that figure is misleading. Yet from such figures as are available it does not seem possible to make the time out of the shed as more than 75 per cent of the total number of hours in the year. Any driver can work any electric locomotive, and such "pooling" may result in a very considerable increase in mileage, but it was assumed in the paper that this was an advantage not shared by the steam locomotive as far as this country is concerned, and it is interesting to gather from Mr. O'Brien that "pooling" ought to be general. With regard to the cost per ton of the electric locomotive, the paper did not suggest that it would ever be reduced to the same cost per ton as the steam locomotive. The electric locomotive is only now being made experimentally, and no parts are standardized for stock manufacture. That alone raises the price, and it is quite reasonable to expect the cost per ton in time to become much less than double the cost per ton of the steam locomotive. When the locomotive as a whole is considered, for the same adhesion the electric locomotive is 30 to 40 per cent lighter than the steam locomotive, while the whole cost of the tender (which Mr. O'Brien omitted from his comparative list) is saved.

Mr. O'Brien's case of the electrification of a line for which sidings formed 55 per cent of the total length, is the best example that could have been given of the difficulties of electrifying some main lines. With all that he says as to choice of system and the possible need of equipping the same lines with two systems, the author is in hearty agreement. It is appropriate that in this connection Mr. O'Brien emphasized the flexibility of electricity supply and the ease with which it could be changed from one form into another.

With reference to Mr. Brook's remarks, the author has

given no consideration to the question of railway companies combining to erect power stations, as such station can supply nothing but the railway, while for a power company the railway demand is but one item in their supply, and the diversity of load may be expected to increase with time. No information, so far as the author knows, is available as to the working of the Reid-Ramsay turbo-electric locomotive.

The annual costs of a locomotive, steam or electric, consist of costs which vary with the mileage (coal and water) and those that do not. To obtain the former the annual mileage for each type must be assumed, which for the passenger locomotive has been taken as the number of train-miles hauled per annum—27,000 miles steam and 40,000 miles electric, as stated in the paper—and it must be remembered that not only the costs given per train-mile, but the actual lump sums given as the annual cost, are dependent on the mileage run in a year by each type of locomotive.

STEAM BOILER WORKING IN ELECTRICAL POWER STATIONS.

By J. W. JACKSON, Associate Member.

(*Paper received 7th April*, 1913, *and read before the* NEWCASTLE LOCAL SECTION *10th November*, 1913.)

A very great deal has been written in the past about steam boilers; so much so, in fact, that it is extremely difficult if not impossible to talk on any new subject under this heading. Fortunately, however, owing to the wide field covered there is sufficient scope for frequent discussion without exhausting the subject.

Re-arrangements of boiler drums, tubes, etc., are of course continually taking place, and in some cases definite advances are being made, but very many of these are only the bringing together of various old ideas.

It is of course granted that better work is being done to-day both in the way of manufacture and operation than was the case 20 years ago. The above remarks should be considered quite general, and the progress made in the steam engine and the steam turbine must not be overlooked. There we see enormous strides. One direction in which progress has been made in steam generation is the superheater. This has recently been developed to meet the requirements of the modern steam turbine. Here highly superheated steam is required because of the increased turbine efficiency.

An important consideration in the case of boilers for electric power stations is the liveliness of the boiler for dealing with variations in the load. The result of this is that the water-tube boiler has been adopted almost universally; and there is really small wonder at this when it is remembered that at least eight of the leading makes of water-tube boilers will permit of steam being raised from cold water to the full working pressure in about 30 minutes, whereas with the big cylindrical type of boiler several hours are required for this purpose.

Circulators have been developed to overcome this difficulty with the cylindrical boiler and are undoubtedly doing good work, but even with circulators the boiler is still very much handicapped, while the ordinary Lancashire type of boiler does not permit of forcing to the same degree as the water-tube boiler.

It will be remembered that in a previous paper* I touched upon this subject. In that Paper the vertical or only slightly inclined straight tube was advocated. Nothing has happened since that time to alter this view.

* *Journal I.E.E.*, vol. 49, p. 220, 1912.

The designing of boilers to fulfil this condition of straight vertical tubes is by no means a simple matter, some difficulty being experienced in designing the drums so as to accommodate the requisite number of tubes without at the same time having to press the drum ends or sides into bad shapes.

It has been seen that where the metal is at all strained in obtaining these deep seatings or facings an irregular stress is permanently put upon the metal, with the result that irregularity of expansion causes local working and ultimately fracturing of the metal at these positions, although the utmost care had been taken in the annealing of the boiler plate at the time of manufacture. This annealing undoubtedly relieves some of the original straining, but it is the shape of the metal that allows the action to be concentrated usually at the sharpest angle of the indentation.

In connection with the design of superheaters, modern competition appears to have called for a superheater of smaller area but placed in a much hotter portion of the boiler, with the natural result that the superheater tubes are overheated and will therefore have only a short life. In addition to this, difficulty is experienced in keeping the tubes in position. This is undoubtedly a mistake, especially after we have got used to superheaters which were designed ten years ago but are free from this objection, as in Fig. 1. These superheaters having ample surface were fixed in the boiler at a distance much further removed from the furnace, with the result that they are much steadier to work and of almost everlasting wear. They also have the advantage that the amount of superheat can be reduced without overheating the tubes. In this latter case, with the superheater in normal full temperature working, the whole of the gases pass through the superheater after having passed so many rows of water tubes. If it is desired to reduce the superheat, a by-pass damper can be opened immediately before the superheater, thus by-passing the superheater with the gases.

The more modern superheater (Fig. 2) does not usually vary the path of the gases at all, but shunts more of the saturated steam past the superheater. This calls for a smaller quantity of steam passing through the superheater, with the result that a lesser degree of heat is transmitted to the steam, thereby allowing the superheater-tube tempera-

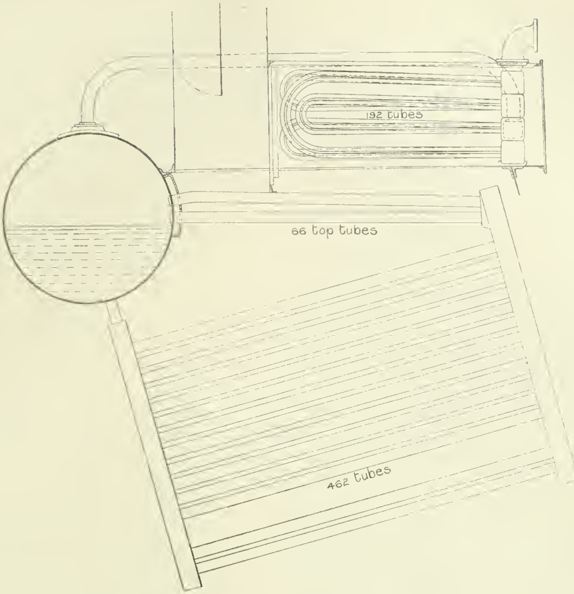

192 tubes
66 top tubes
462 tubes

FIG. 1.

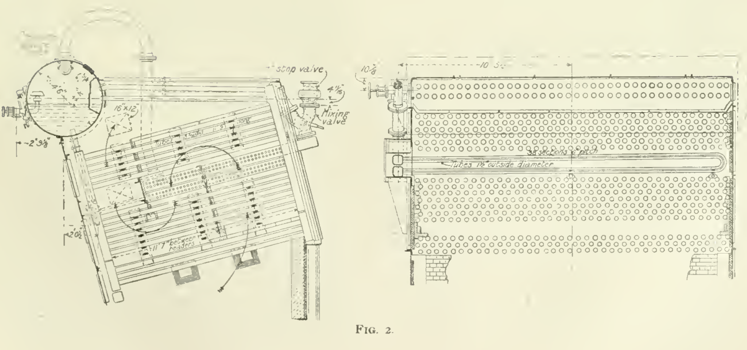

stop valve
Mixing valve
between headers

FIG. 2.

ture to rise so high that corrosion or oxidization occurs inside and outside the tube.

It would appear that the reason for fixing the comparatively small superheater in such a hot position of the boiler is due to first cost; the new superheater can of course be made considerably cheaper, but the difficulties in operation are increased as regards maintenance, reliability, and control. The scheme usually means that the modern superheater is fixed between the main water tubes of the boiler, with the result that "sooting" of the boiler becomes a difficult matter; also such a number of small tubes being bunched together in such a hot position may allow of the soot clogging up certain portions of the path of the gases, the degree of superheat being thereby affected considerably by the cleanliness of the boiler, that is to say the freedom from soot. When certain portions of the path of the gases become clogged with soot, the gases are then concentrated on the narrow passages, with the result that a greater amount of heat is brought to bear on those portions, which causes more rapid oxidization of the metal, and so shortens its life.

This clogging of the gas passages continues until the amount of superheat falls to a comparatively low figure, by which time the gas passages throughout the boiler have become so clogged with soot that a thorough "sooting" is necessary. This trouble is one that requires most careful consideration when the lower grades of fuel are handled, such as duff coal, etc. In such cases a considerable amount of soot or dust is blown through the gas passages, and causes trouble from the clogging of the passages in perhaps a quarter of the time that would be experienced with a higher grade of fuel.

The more generous superheater fixed beyond the first bank of tubes being of ample size for its work because of the lower temperature of the gases, is much less sensitive to the fouling of the passages by soot, the reason apparently being that the boiler becomes choked up with soot amongst the first four or five rows of tubes from the fire; in fact, with certain grades of fuel clinker is burnt on the tubes until there is scarcely a passage left at all. Under these conditions it will be seen that the superheater is subjected to about the same gas temperature as before, and continues to give almost the full superheat.

It has just been mentioned that higher superheat is used now than was required a very few years ago. We are undoubtedly at the beginning of the period when really high superheated steam is coming into use, and steam temperatures of from 700° F. to possibly 900° F. at the turbine stop valves are likely to be required before very long. Under these conditions it will be seen that if the superheater of the future is fitted in such a hot position of the boiler as in the case of some existing superheaters, troubles will increase somewhat alarmingly. Again, several superheaters are made with bent tubes. There does not appear to be any serious disadvantage in using such superheaters so long as the water can gravitate to a header. If a superheater tube is bent so that it cannot drain itself at the bottom, as in Fig. 3, serious corrosion or possibly complete clogging of the tube is liable to occur; but even this trouble can be lessened if the superheater is kept well up in the boiler so that it does not normally become flooded when the boiler is at rest. Here again, however, Fig. 1 offers a good solution, as owing to the gas by-passing the superheater there is no danger of the latter being flooded or of its being overheated when starting the boiler. Fig. 4 is a good design when kept well up above the water level. In this connection attention may be called to the fact that there is always a considerable amount of risk with a superheater that has to be blown out before the boiler can be put on load; and from this point of view alone it is advisable to stipulate that the superheaters be kept well up above the boiler water-line and also that the superheater be considered, so far as operation is concerned, a portion of the main steam pipe, that is to say, that the boiler should not be fitted for the main steam with a main saturated steam pipe arrangement.

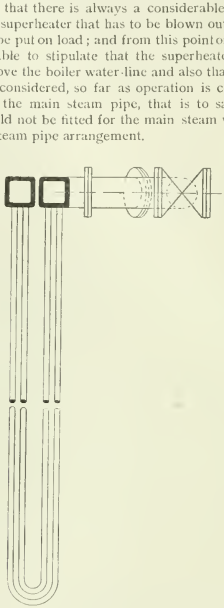


FIG. 3.—Type of Superheater adapted to a Lancashire Boiler.

Another trouble with the modern superheater is that owing to its comparatively small surface a considerable drop in pressure takes place when the boiler is being worked at its normal full load, this drop amounting to as much as 10 to 15 lb. per sq. in. at the normal full-load rate of working, whereas with the older superheater a drop of about 5 to 7 lb. takes place. The difficulty of overhauling and cleaning the exterior of the modern superheater is also considerable, this being due to the narrow space provided, it being almost impossible for a man to get into the space and carry out the necessary work. The older superheater being fixed at the top of the boiler allows of the superheating casing being dismantled entirely, so giving very thorough and complete access.

With regard to the position of the main steam drum or drums, some consideration is required as to the position at which the water-gauge fittings are to be attached. If the drums are placed parallel to the path of the gases then

the front of the drum should be set at a higher level than the back of the drum, while if the drums are at right angles to the flow of the gases the front drum should be elevated and the back drum lowered in comparison with the level of the centre drum. In actual practice in the case of a boiler with three drums set at right angles to the flow of the gases, the length of the boiler from the front to the back being about 16 ft., there is a difference in the water levels between the back drum and the front drum of as much as 12 in. when the boiler is being steamed at normal full load. The reason for this is not difficult to see. It will be remembered that nearly 75 per cent of the total evaporation of the boiler takes place in the front two or three rows of tubes. The bubbles of steam rising up the tubes at a fairly high rate displace the water in the tube, and so set up a rapid circulation ; moreover, the water in the front drum is quite full of large and small bubbles of steam which have the effect of lowering the density of the water ; and, further, friction is set up in the water-circulating tubes by the water flowing from the front drum to the middle and back drums to repeat again the cycle of circulation. There does not appear to be any disadvantage whatever in elevating the front drum by as great an amount as that indicated. In elevating the front drum by 12 in. above the level of the back drum it will of course be seen that a fairly long water-gauge glass is required to cover fully the variation in water levels. This, however, is an advantage rather than otherwise, and in following this scheme out a lower water level can be maintained with much greater safety than is at present experienced ; that is to say, by elevating the front drum the water level throughout all the drums will be the same mean level under working conditions, and by carrying as small a quantity of water in the drums as is reasonably safe, greater freedom from priming, when dirty water is carried, is obtained. This question of priming is of great importance,

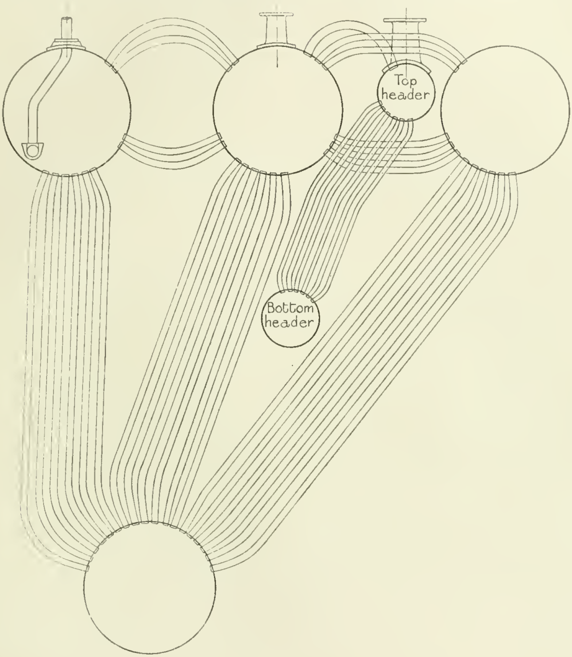


FIG. 4.

whether the steam is required for reciprocating engines or turbines, and any scheme that can be put forward for reducing this difficulty must receive attention.

Another difficulty in connection with priming is the corrosion of the steam space of the drums and of the steam and superheater tubes. The steam rising from the water surface heavily charged with moisture comes in contact with the heated surfaces of the upper portion of the drum and steam-connecting and superheater tubes, and is liable to set up very serious corrosion, which in a comparatively short time will completely destroy the tubes. It is quite easy to overcome this trouble, so far as the drums are concerned, by painting the internal surfaces of the drums with any of the first-class bitumastic paints that are now on the market. This process of painting with bitumastic paint has now been carried out on boilers for at least five to six years with completely satisfactory results, and if the paint could be easily applied to the surfaces of the cross-over steam and superheater tubes there is little doubt that the trouble would be got over by the same means. From the above remarks it will be seen that comparative priming is undoubtedly the real cause of the trouble, and this priming is quite possibly due to the comparatively small steam space available in the drums.

Boiler Furnace.

One of the most notable advances made in the present-day steam boiler is that of smokeless working with ordinary bituminous and low-grade coals. In a very short time it ought to be possible for the British Navy and the large shipping companies to run their boilers on ordinary bituminous coal, the first cost of which is so much less than that of the higher grade Welsh coal. It is of course admitted that bituminous coal can be obtained of equal value to the best Welsh steam coal at something like half the cost. The only real difference in the value of the two coals is the smokelessness of the one with a particular type of boiler furnace. One reason frequently advanced against the old Lancashire boiler for electrical power stations was its smokiness, and the same difficulty applied to some of the early water-tube boilers—that is to say, the water-tube boilers built about 15 years ago. In these cases the space between the fire grate and the tube surface was extremely small, with the result that the gases were chilled before combustion was completed. To obtain a good combustion a temperature of about 2,500° F. to 3,000° F. is required in the combustion chamber, while the temperature of the outside of a water tube or the furnace side of a Lancashire-boiler tube rarely exceeds 400° F. Therefore once the gases became chilled there was little possibility of smoke being avoided.

Experiments were made some years ago with the Lancashire type of boiler by lining the first part of the furnace with firebricks; this gave very much improved results so long as the firebricks lasted, but being subjected to a high temperature at very close quarters they had only a short life.

With the modern water-tube boiler a very large combustion space is provided, and a great deal of this combustion space is lined with a refractory material, high-grade firebricks usually being employed for this purpose. The firebrick becomes heated up to a fairly high temperature, but being sufficiently far removed from the heart of the flame it does not suffer at a prohibitive rate and so allows combustion to be almost completed before the heated gases are allowed to come in contact with the comparatively cold metal surfaces.

Another important reason for the smokelessness of the modern boiler is of course the mechanical stoker, where the fuel is gradually heated up at a comparatively slow rate or in comparatively small quantities so that there is no great rush of gas into the furnace at any moment. This scheme of making the furnaces with refractory linings becomes of considerable importance when low-grade fuel has to be employed, as unless the furnace temperature is maintained this fuel cannot be dealt with. One of the best illustrations of this is the ordinary refuse destructor. The ordinary refuse employed has a very low B.Th.U. value, but yet it is possible completely to destroy all organic matter by utilizing refractory linings in conjunction with heated air supplied under pressure. The refuse destructor should therefore be almost the starting-point wherever low-grade fuels are to be employed.

Air leakages into the furnace are of very considerable importance, and this question probably requires the largest amount of attention in boiler working from the point of view of efficiency. With the ordinary induced-draught system, which is very generally employed, air leakages can occur over very wide areas, and it is often an extremely difficult task to ascertain the starting-point of the leak. One of the best illustrations of the effect of air leakage on boiler furnace brickwork can be seen on boilers using gas firing, where practically the whole of the furnace brickwork is heated up to almost the same temperature. Those places at which air leakage occurs show up as black spaces over the brickwork inside the furnace. These places are of course readily inspected by means of the usual furnace inspection doors. Again, in the case of a chain-grate stoker using coal with a calorific value of something less than 10,000 B.Th.U.'s per lb., an air leakage into the furnace towards the front end of the boiler has such a bad effect on some grades of coal as quite to put the fire out if an attempt is made to drive the boiler at even the normal rate of working.

The CO_2 indicator is of course of great assistance in locating air leakages, but it only indicates that a leakage is taking place. It is of great value, especially when it is of the recording type, not only to the officials but also the firemen, and firemen after having worked with this apparatus for a very short time very much appreciate its uses and gain such information by its use that considerably improved results are obtainable. Wages for the firemen and others connected with some steam plants are controlled by the amount of CO_2 indicated by the recorders. This is a scheme that has a great deal in its favour, although at the same time other features have to be closely watched. It is quite possible to get a very high percentage of CO_2 in a furnace, and so earn a big bonus, without effecting any real improvement in the coal consumption of the station. This would of course occur where the ash was allowed to leave the station without proper supervision, the reason being that with reasonably good brickwork it is possible to show a fairly high percentage of CO_2 without going to great trouble by allowing a rather large quantity of fuel to go over the back-end unconsumed. This difficulty, however, would in some power stations be

very easily got over by the amount of noise made by the workmen handling the ashes, as in the event of such an extreme case of negligence such men would have an extremely difficult task.

A new page in boiler history was recently opened by Professor Bone and Dr. Nicholson. The particular line of research adopted by Professor Bone has been that of surface combustion. In this case the ordinary furnace is eliminated, but at present the apparatus has only been designed for use with the cylindrical type of boiler of very short length, combustion taking place within the fire tubes. This scheme calls for a very high rate of evaporation per square foot of heating surface, thus requiring that very suitable feed water be supplied to the boiler.

So far as can be seen at present, the field for this scheme is somewhat limited, the fuel employed being cleaned gas. The great point in its favour that makes it so much worth consideration is the high thermal efficiency. It is claimed that boilers working in commercial practice are giving over 90 per cent thermal efficiency, while the evaporation per square foot of heating surface has been raised to 35 lb. Apparently the power required to drive the auxiliaries such as the fan, etc., is somewhere in the neighbourhood of from 4 to 6 per cent of the total power developed by the boiler.

Dr. Nicholson's scheme can apparently be applied to any of the usual commercial boilers by re-arranging the gas paths. The furnace remains much the same as before, the chief idea being to pass the gases after combustion over the heating surfaces at a very high rate of speed. In the case of Lancashire and Cornish boilers the furnace tube for a portion of its length is fitted with a firebrick plug, leaving a very narrow space between the plug and the heating surfaces for the gases to be forced through. In passing the gases over the heating surfaces at this high rate of speed a considerable number of eddies are formed, with the result that the film of comparatively cold gas is driven away from the heating surface, thereby permitting a more ready transference of heat. The other great advantage of this scheme is that owing to the high speed at which the gases flow it is possible to reduce the temperature of the outlet gases to below 200° F., with the result that the latent heat of the steam contained in the gases is recovered. With some types of coal this is a very considerable amount.

It is stated that owing to the gases being carried over the heating surfaces at such a high rate of speed no corrosion due to the condensation of sulphuric acid takes place in either Professor Bone's or Dr. Nicholson's schemes. So far as can be seen at the present time it is possible for the overall efficiency of a commercial boiler to be improved by from 2 to 7 per cent over the best modern boiler practice. Dr. Nicholson's scheme like Professor Bone's scheme requires a very considerable amount of power in producing the necessary draught. Of the two schemes perhaps Dr. Nicholson's is the more promising, as under this arrangement it is possible to use coal in the ordinary boiler furnace. This in turn means that the usual ash-handling arrangements can be adopted, whereas in Professor Bone's scheme it would be necessary that a gas producer be built before the boiler could be got to work in a very great number of steam-raising plants; and those who have had experience with gas producers know that their working is by no means simple, while the efficiency of the gas producer is such as would quite eliminate the saving to be effected on the steam boiler unless a by-product recovery plant is used in conjunction with the gas producer.

The selection of firebricks is one that naturally requires very careful attention. The particular make of firebrick to be used depends not altogether upon the quality of the brick but to a great extent upon its character. Some firebricks with great reputations run to slag very quickly indeed, while again other firebricks practically unknown do excellent work with the same coal. There is of course no great wonder at this when it is remembered that the sulphur content of coal varies very considerably, while again some coals contain a fairly considerable amount of impurity such as fireclay. This fluxes some makes of bricks very badly, and on examining the furnace after quite a short run it will be found that the molten firebrick or slag has run down the underside of the furnace arch, cutting quite deeply into the firebrick and practically making rivers running down the side walls and on to the grates, with the result that the fires quickly get into a very bad condition and need to be cleaned by means of a long slice as frequently as once per hour.

The above is undoubtedly one of the explanations of the variable reports received from time to time regarding the various makes of firebrick; therefore it seems that when difficulty is experienced, experiments must be made with various firebricks until a suitable make is discovered. In some cases natural stone, very high in silica content, taken direct from the stone quarries has been used with very good results.

It will generally be gathered from the above remarks that a good furnace is one that allows plenty of room for combustion and is well lined with a refractory material, as undoubtedly the theory is being more and more appreciated that the boiler has the function of absorbing the heat delivered to it from the furnace, while the function of the furnace is to produce the heat, and the requirements of both must be kept in view if good results are to be obtained.

The important idea to keep in mind when arranging furnaces is to surround the fire as much as is necessary with refractory lining, so as to permit of the high temperature being obtained through complete combustion before the flame or hot gases are allowed to come into contact with the heating surfaces, and that is almost the only value, but a very important one, that firebricks have in the furnace.

Stoking Gear.

Boilers have for a great many years been fired by hand, and this still appears to be the case with marine boilers in both the mercantile marine and the Navy.

In view of the success that the machine-fired stoker has met with on land boilers, it is very difficult to explain why marine boilers are still fired on what should be called an old-fashioned principle. Hand firing has undoubtedly some serious disadvantages, one of these being the frequency with which the fire-door needs to be opened, thereby admitting a great rush of cold air, which more or less cannot be utilized to advantage, but which for the time being lowers the efficiency of the furnace.

It may of course be that one of the reasons why hand firing is still used is that a very great number of the old-

fashioned cylindrical boilers are still in use, which type of boiler offers some difficulty to the principle of the machine-fired stoker. Those, however, who have had experience with boilers on land with hand firing must realize that for the amount of steam required an exceedingly high cost of labour is involved, but it is only when a fairly large battery of boilers becomes necessary that this point may be really appreciated. On the other hand, those who have a number of machine-fired boilers to attend to, realize that firing under the new conditions with many of the modern stokers is a very much easier task, although giving an output of from 10 to 20 times as much steam as was the case with the hand-fired boiler. An important consideration in favour of machine firing is the regularity with which the fuel can be fed into the furnace, and this generally means that a high percentage of CO_2 can be obtained under equal conditions as compared with the hand-firing scheme, the liability to form smoke being at the same time reduced.

In populous districts, and also in the Navy, smoke commands considerable attention. Some of the largest boiler installations in the country have been fired for many years by machine stokers under very variable loads and conditions, and it is very rarely that smoke is seen to issue from the chimneys. The author has also a particular instance in mind where a good-class machine stoker now at work under some boilers replaced a stoker which was supposed to be a machine-fired stoker, but which was so erratic in its general conduct as practically to amount to a hand-fired stoker, with the result that violent smoke was emitted over considerable periods. This was due to the firemen having continually to pull the fire about in order to get steam at all, and even after all this labour only about half the steam was available that should have been obtained, and which was obtained with the better type of stoker. Machine firing is of course of the greatest service where coal is used in a somewhat finely divided state, and coal in this state is of course the most difficult to deal with by hand firing. It is possible now to handle coal in the finest possible state of division without causing smoke or encountering any other than the usual difficulties, that is to say that "duff" coal can be as easily handled as "nuts."

Years ago mechanical stokers were made of the "sprinkler" type. These did very good service, but were often accused of causing smoke. In almost all cases where smoke was experienced with this type of stoker no firebrick lining was fitted to the furnace, therefore the stoker was unfairly charged with that disadvantage. The "sprinkler" stoker was followed by the "coker" stoker. This also did good work and was more suitable than the "sprinkler" for certain classes of coal, but it also caused smoke when the furnaces were not lined with firebrick. The "coker" was in turn followed by the "underfeed" type, which caused as much smoke as any of them when it was fitted in furnaces not lined with firebrick, and running parallel with some of these stokers was the chain grate, made by various manufacturers. There are some chain grates working in neighbouring collieries that were made by a firm of ironfounders near Durham which have given most excellent service for nearly 20 years, and although somewhat rough they are working under just the same main principle as we see to-day in the modern chain-grate stoker. This stoker has also given very good service, but will smoke under unsuitable conditions. Some of these stokers are much more suitable for certain types of fuel than others. It is undoubtedly a fact, however, that all stokers may be good, but that some will do much better work under certain conditions than others. It is of course the usual thing for the designer to claim that his stoker is the best all-round stoker, and in his own particular line he is possibly correct.

One particular advantage of the chain-grate and step-grate stokers is that they allow the ash to be handled more or less automatically, that is to say the ash is delivered by the stoker on to or over the dumping bars at the back end of furnace. With the old pattern chain-grate stoker a considerable amount of labour was required to pull the ash and clinker over the dumping bars on to the dumping doors; this is owing to the fact that dumping bars of considerable thickness and length are necessary with the old type of chain-grate link. This length is used with a view to covering up the openings in the link at the time that they begin to go round the back sprocket. Links have recently been developed which allow of a dumping bar being fitted as short as is desirable; the determining factor in this latter case being that a slight check to the ashes, etc., is necessary to allow of complete combustion occurring at the back end, otherwise good fuel may be carried over in fairly considerable quantities. A fairly big boiler plant is of course fitted with the usual ash conveyers for loading up the ashes into the railway trucks or barges.

It is of course of considerable importance that the ashes should be handled mechanically, as otherwise very high costs for labour and other labour difficulties will occur. This automatic principle is equally necessary for putting the coal into the bunkers. Nobody would suggest for a moment that the appliances required for this class of work are capable of operating without trouble from breakdowns, etc., but the trouble and cost of operation is nothing compared with what would undoubtedly be experienced with hand labour. A better scheme than the ash conveyer has been developed and is now being solely relied upon for some large boiler plants, and it is giving a very considerable amount of satisfaction. The principle roughly is that a large cyclone chamber is fitted above an ash bunker; the cyclone chamber is connected up to an exhauster of fairly large capacity which will create a vacuum of as much as 4 in. of mercury. Another pipe is taken from the cyclone chamber and has a number of openings in it, the openings corresponding with the number of ash hoppers under the boilers. An ash crusher is fixed on wheels and is capable of being moved from one ash hopper to another; it is driven by an electric motor and crushes the ash as the latter is allowed to issue from the boiler ash chute, in which condition it is allowed to fall into the suction pipe. The draught created by the air exhauster at this pipe is so great as to cause the ash and clinker to be drawn up the pipe to a considerable height, where it is ejected through the cyclone chamber into the ash bunker. A very important advantage that this scheme has over any other ash-handling plant is its freedom from dust. The only place where dust can be met with is at the point where the ash is loaded up into the railway trucks from the ash bunker, and even this can be dealt with by fitting spraying pipes inside the ash bunker.

A somewhat similar method of dealing with ashes has been in use for several years, more especially for marine work, and in a few instances for land work. In this case water pressure is used for ejecting the ashes. The apparatus is usually spoken of as Sees ash ejector. In one particular case two equipments have been placed in series, and ashes are being delivered through the discharge pipes as far as one-quarter of a mile away from the boiler-house. This scheme is a very good one indeed in many positions, but it is not as free from dust nor is it as easy to handle as the pneumatic type of plant.

Feed-water treatment has always received a considerable amount of attention. There is a very good reason for this, and it is extremely difficult to lay down any hard-and-fast rules for treating feed water; but wherever the opportunity presents itself of roughly analysing the solid matter in the boiler water and the amount of hardness of the make-up water, the simple system of treatment, generally with soda ash and lime, should be adopted. A multitude of makes of boiler compounds are on the market, which will soften the water more or less as claimed, and possibly allow more abuse of the boiler than the simple scheme of soda ash and lime does; that is to say, the water can possibly be much more overtreated with compositions without such bad effects. It should be borne in mind, however, that very few boiler compositions can deal with the softening of feed water at anything approaching the cost of that of the lime and soda system.

Boiler corrosion has always been a most difficult subject, and it is possibly not much nearer being solved now than ever it was. One of the most formidable reasons for this is the impurities in the metal of which the boiler shells and tubes are made. Various methods of treating the interior of the tubes with some paint that to some extent will electrically insulate the water from the metal have been introduced. Such painting will undoubtedly reduce the trouble in that respect, but on the other hand it prevents the efficient transference of heat through the plate. Very frequently a compromise has to be made between two or three evils.

Various electrical schemes are now being tried for overcoming the local action on the boiler tubes and plates, by concentrating it on renewable plates located inside the boiler. This promises well, but it must be applied with the utmost care or the troubles may be much increased.

Discussion.

Mr. Turnbull. Mr. C. Turnbull: The author wonders why much use has not been made of mechanical stokers at sea. The great difficulty is that mechanical stokers nearly always use small coal. At sea the coal is mixed—some is small and some is big—and if it had to be broken up the additional expense incurred would be greater than the saving effected by the use of mechanical stokers.

Mr. Baker. Mr. H. H. Baker: In dealing with the question of superheaters the author shows a strong preference for the arrangement illustrated in Fig. 1. No doubt this is a very satisfactory arrangement, but I do not think it is quite fair to assume that it is solely the cost of manufacture that has brought about the change in position to that shown in Fig. 2. The necessity of obtaining a larger output per boiler, the fact that the width and depth are limited by the stoker, and the increase in the temperature of the steam to 650° or 700° F., have, I think, made it necessary to place the superheater lower in the furnace. The author considers that the arrangement illustrated in Fig. 1 is much cheaper as regards maintenance. I doubt whether this will be borne out in practice.

Mr. Selvey. Mr. W. M. Selvey: As regards the variation of the superheat with the condition of the boiler, I think Mr. Innes and the author are both correct. I should expect a clean boiler to give a lower superheat, which would gradually rise as the boiler tubes nearest the fire got dirty, and finally fall again as the superheater tubes got dirty. With reference to the proportion which the author has given for the concentration of the evaporation in the front tubes, I should be inclined to put this a little lower, probably not greater than 60 per cent, having in mind the actual temperature of the gases impinging on the tubes, as measured in our tests. I feel inclined to protest against the view that the Bonecourt boiler and the work of the late Dr. Nicholson have opened a "new era" in boiler practice. I think this statement is due to a want of appreciation of what has already been done. Outlet temperatures, certainly within 100° F. of the lowest proposed in these schemes, are being obtained with plant such as that outlined in the paper. The result is practically within 3 per cent of the efficiency proposed, and these boilers use raw coal of a very low grade. The extra fan power will more than account for the gain to be expected. The Bonecourt boiler uses a fuel which is mainly hydrogen, and it is therefore proposed to condense the steam in the flue gases so as to render its latent heat available. Apart from coke-oven gas, which has only a very limited application, I take it that such a boiler involves the use of a producer. A producer without by-products means sacrificing 15 per cent of the efficiency. With by-products the conditions are so different that it would be quite impossible to go into them now. There is an impression—which I probably shared—that if the outlet gases are cooled below 212° F. part of the steam in them is condensed. On looking closely into the matter I find that with good combustion of Mond gas no condensation would take place above about 120° F., and with the products of combustion of coal which is burnt in an ordinary manner the temperature is nearly as low as 90° F. This led to a conclusion which was new to me. Those who have read Professor Dalby's paper * on heat transmission before the Institution of Mechanical Engineers will be familiar with the idea of a cold film of gases next to a metal surface. What the above calculation leads to is that the temperature of the metal surface, *i.e.* the economizer tube, must not fall to the "dew point" of the gases if condensation is not to occur; that is to say, in order to prevent corrosion the temperature of the feed water is the important matter. This is generally known in practice, the working temperature being kept at 90° F.; but the additional information is, that provided the feed temperature be kept up there is no objection, certainly in the case of coal-fired boilers,

* W. E. Dalby. Heat transmission. *Institution of Mechanical Engineers, Proceedings*, p. 921, 1909.

Mr. Selvey. to having the outlet temperature as low as those proposed in the new schemes. The problem resolves itself into a question of the value of the extra steam raised and the cost of raising it. Moreover, by baffling existing economizers so as to make them more "contraflo" by the help of a little extra draught, say another 1 in., the present temperatures can easily be further reduced. In connection with brickwork the sulphur that the author speaks of is accompanied by iron, and it is the fluxing effect of the iron-oxide on the bricks which produces the result described. For this reason common bricks (which if of purer clay are less easily fluxed) are sometimes found to be more satisfactory than expensive bricks. I do not know why a mechanical stoker has not been developed for marine work, but I suggest that this is partly because the "ideal" has always been an oil-fired boiler.

Mr. Baxter. Mr. W. BAXTER: I think it is generally admitted that where steady steaming is all that is required the Lancashire boiler is very satisfactory. It would be interesting to know what type of turbine blading the author would recommend for use with the highly superheated steam which he prophesies will come into use in the near future. With regard to the author's remark that a refuse-destructor design should be the starting-point wherever low-grade fuels are to be employed, it is a well-known fact that the earlier destructors were not a success simply because the theory of combustion was not properly understood. It is surprising what a large amount of air will leak through ordinary well-joined brickwork; and while this is a point that receives every attention in power stations, it is very frequently neglected in collieries and small works. I note that the author has a good word to say for the "sprinkler" type of stoker, but other conditions being equal it seems impossible for this type of stoker ever to be as good as the "coking" type, as the gas given off by the fuel which is thrown towards the back of the furnace never has time to be consumed properly and simply produces smoke. The use of soda ash and lime appears to give excellent results with some waters.

Mr. Clemitson. Mr. A. R. CLEMITSON: The author's advocacy of vertical straight-tube boilers is more significant when one bears in mind the considerable experience that he has had with boilers of various types. It must be admitted that the majority of boilers working in this country are not designed on those lines; but on the other hand there is a sure tendency among not only power-station engineers but also engineers of commercial undertakings to get rid of horizontal tube boilers, all of which are designed on more or less wrong principles, and of boilers with bent generating tubes, and to go in for vertical straight-tube boilers. The design of a superheater and its position in the boiler depend of course very largely upon the amount of superheat that is desired; but as there is certainly a tendency towards high-temperature superheated steam, the superheater must be placed in such a position that the temperature of the gases will be in the neighbourhood of 1,500° F. It has been suggested by a previous speaker that it is not desirable to by-pass any of the superheated steam, since with a change in the output of the boiler the amount of heat on the furnace side would likewise vary, and thus whether the boiler is working on light or heavy loads the temperature of the superheat would not vary to any extent. While this is practically correct, it must be remembered that it is very often the condition and arrangement of the steam engine which determine what the final temperature of the steam should be; and it will therefore be necessary to have means of controlling the temperature under all conditions of load. The regulation obtained by by-passing some of the saturated steam is quite satisfactory. I should like to ask the author what amount of saturated steam could safely be by-passed with the arrangement shown in Fig. 2 without causing any damage to the tubes, assuming the superheater is designed under normal conditions for 200° F. superheat. The author has made a point of the clogging up of the superheater tubes, which must occur more particularly with design No. 2; this inconvenience, however, is reduced to a minimum in the Woodeson superheater, which is much more accessible. Reference is made in the paper to highly superheated steam, and the author points out that temperatures of 700° F. to 900° F. are likely to be required before long. It may be of interest to mention that Messrs. Clarke Chapman & Co. are at present making two large boilers for Luton Corporation, and also one for Loughborough Corporation, where the temperature of the superheated steam is 700° F. I do not see any necessity for the large drop in pressure that the author says takes place in the modern superheater; it appears to be only a question of arranging a sufficient area through the superheater tubes for there to be no appreciable drop at all. I quite agree with him that large combustion chambers are essential if high furnace temperatures are to be obtained. In Lancashire boilers and often in horizontal water-tube boilers the gases are chilled before combustion is completed, and therefore the temperature of the furnace never rises sufficiently to give the high efficiency that can be obtained with water-tube boilers designed with large combustion chambers. As pointed out by the author, much importance should be attached to the percentage of CO_2 found in the escaping gases; and as this can be so much affected by air leakage through the brickwork, I should like to ask him whether he has found much improvement in this direction in boilers enclosed in a steel case.

Mr. Vernier. Mr. C. VERNIER: Not only does the Bonecourt boiler suggest the possibility of making better use of our fuel, but compared with present boilers it appears to save considerable space, which I think is an important point in connection with power stations. I should like to ask the author what are his views with regard to the future possibilities of gasifying coal. I have recently given a good deal of attention to the subject, and it seems to me that it might pay to adopt this method in some cases, in view of the high value of the by-products recovered. Any of the following methods of gasifying coal with recovery or by-products could be used: (1) The coal might be coked into furnace coke in by-product-recovery regenerative coke-ovens and the surplus gas utilized for burning under steam boilers; (2) the coal could be destroyed in gas producers; (3) a combination of these two methods might be used, the coal being first coked at a low temperature so as to recover the more volatile constituents, and the coke being then finally destroyed in gas producers. In each case the by-products would be recovered. I assume that in each of these

Mr. Vernier. cases a good coking coal of 15,000 B.Th.U. per lb. (33,600,000 B.Th.U. per ton) would be used. The cost of this I have taken at 13s. 6d. per ton. In order to ascertain the value of the gas recovered, I have taken the thermal value of the gas when burned under boilers as only 60 per cent of that of the coal if burned direct. In the former case one would have to get 124,500 B.Th.U. for one penny, whereas coal would yield 207,400 B.Th.U. for the same sum. The price obtained for the sulphate of ammonia has been taken at £11 10s. per ton, which allows about 30s. per ton for working expenses (sulphuric acid, bagging, etc.). The first method is limited in its application to those districts where there is a demand for furnace coke. The by-products recovered would be approximately as follows:—

	s.	d.
10 gallons of tar	3	0
30 lb. of sulphate of ammonia	3	0
13 cwt. of furnace coke at 21s. per ton	13	6
5,500 cub. ft. of gas of 650 B.Th.U. (3,474,000 B.Th.U. at 1d. per 124,500 B.Th.U.)	2	4
	21	10

The second method is that which is more suitable for use with gas engines, of which an interesting example is the plant installed a year or two ago by the Corporation of Accrington. In this case it is possible to quote some actual figures from the published results. The plant is by no means a large one, consisting of only two 1,000-h.p. gas engines, and its cost is stated to be £18·75 per kilowatt, including some special work in connection with difficulties encountered on the site. About 85 tons of coal are gassified per week, and the by-products recovered per ton of coal are:—

	s.	d
98 lb. of sulphate of ammonia	10	0
$2\frac{1}{2}$ cwt. of cheap tar at 10s. ton... ...	1	3
	11	3

The fuel consumption is 1·6 lb. of coal per unit, costing 0·125d., and the value of the by-products recovered is equivalent to 0·07d. per unit. The third method, which is likely to prove of the greatest value, retains the more volatile constituents of the coal in the tar and tar oils. One of the chief difficulties in the way of gasifying coal, unless it is completely destroyed in a gas producer, is to find a suitable market for the surplus coke, as there is already a glut of coke from the gas-works. The final destruction of the coke, which on account of the low coking temperature retains the greater part of the nitrogen, disposes of this difficulty, however, while at the same time enabling the maximum value of the by-products to be recovered. Alternately, of course, the coke might be used direct to fire steam boilers. The value of the products recovered in this case would be somewhat as follows:—

First low-temperature carbonization—

	s.	d.
(1) 20 gallons of tar and tar oils ...	6	0
(2) 12 lb. of sulphate of ammonia ...	1	2
(3) 13 cwt. of tar-free coke	—	
(4) 5,500 cub. ft. of gas of 650 B.Th.U. (3,575,000 B.Th.U. at 1d. per 124,500 B.Th.U.)	2	4

	s.	d.
Brought forward	9	6
Final destruction of the 13 cwt. of coke (Item 3) in gas producers—		
(1) 50 lb. of sulphate of ammonia ...	5	0
(2) 150,000 cub. ft. of gas of 130 B.Th.U. (19,500,000 B.Th.U.) ...	13	0
	27	6

In the latter case we see that the value of the gas and by-products recovered is greatly in excess of the original cost of the coal, and this should leave ample margin to cover interest, depreciation, and labour on the gas plant. Much depends, of course, on the future stability of the market for sulphate of ammonia; but it is stated on good authority that the present output could at least be doubled without affecting the market.

Mr. Wright. Mr. J. WRIGHT: There is no doubt that any economies that can be effected in the boiler house far outweigh those which can be made on any other part of the plant. I am glad to see that the author advocates the vertical or slightly inclined tube boiler, which has many advantages. Particularly is it suitable for the conditions that exist in this locality, where so much blast-furnace gas is used as fuel and a large quantity of dust has to be dealt with. The vertical type of boiler is much more easily kept clean. I was also glad to note that the author places so much importance on the superheater, as unless the steam is to be used for work where a superheat is not advisable it seems to me that the superheater is an essential part of every water-tube boiler. Superheaters could be fitted with advantage in every case. I see that the author's views on superheating coincide with some notes which I gave last year before this Local Section. That is to say, where only a small part of the steam passes through and necessitates a mixing valve, superheaters are not advisable, apart altogether from the corrosive effect that the author mentioned. While I agree with the author that it is advisable to have a larger superheater baffled by a section or sections of the boiler, I do not think that it is quite the arrangement of superheater which will be asked for in the future. With the high superheat called for at the present time and the still higher superheat that will be demanded in years to come, the ideal superheater will be the armoured type placed in the hot part of the boiler—I refer to a heater such as the Foster superheater, where the armouring takes the form of cast-iron fin rings threaded over the tubes. The protective effect of the cast-iron rings, together with the large heating surface and the accumulative effect of the heat in cast iron, form a superheater for which there seems to be a future. Another good arrangement has been adopted by some of the boiler-makers on the Continent, where the superheater is placed in a chamber adjacent to the combustion chamber and the flow of the gases is controlled. I agree with the author that it is better to control the superheat by means of the gases than by shunting part of the steam. While the modern superheater has its disadvantages, the pressure drop mentioned by the author seems to me excessive, unless of course some of the tubes have been burnt out and plugs fitted. There is something to be said for the elevation of the front drum of boilers, but this only applies to some types, and would have to be taken into serious consideration in designing the boiler. It would be impossible to lay down any hard and fast rule as to how

Mr. Wright. much the front drum should be elevated. With regard to the question of air control in relation to combustion, this is a most important point so far as the efficiency of the boiler is concerned. I should like to ask the author what percentage of CO_2 he would expect to get in everyday working. I think it is impossible to give too much attention to this question of air control, especially when we know that with 8 per cent of CO_2 the losses are three or four times greater than with 14 or 15 per cent of CO_2. I have often thought it would be a very good thing if some permanent form of radio-pyrometer could be fitted to the combustion chamber so that the fireman could observe the effect of air control apart from the amount of CO_2 recorded. What has been the author's experience of the flat arch as against the sprung arch? I have known the combustion to be improved considerably by the fitting of flat arches, owing to the better distribution of the gases across the furnace and to the gas not having the same tendency to draw to the centre of the arch. Has the author had any experience with water backs? I refer to a block mounted on a trunion at the back of the grate and acting as a brake on the fuel. Ordinary small ash can normally get through, and large clinkers are heavy enough to swing the block on its trunion so as to pass through to the ash-pit. The block simply acts as a brake on the fuel and so prevents air leakage at the back of the grate.

Mr. Taylor. Mr. L. TAYLOR: As the author has pointed out, the water-tube boiler has been adopted almost universally on account of the ease with which it deals with fluctuations in the load, and no doubt partly on account of its efficiency. He also remarks that the designing of boilers with straight vertical tubes is by no means a simple matter, some difficulty being experienced in arranging the drums to accommodate the requisite number of tubes without at the same time having to press the drum ends or sides into bad shapes. I should like to point out that the Nesdrum water-tube boiler exactly fulfils the author's ideals. The tube plates and the manhole ends of the nests of tubes are dished in the same manner as the main steam and water drum ends to suitable radii so that no deep seatings are required and the metal is not strained. The tube plates and the manhole ends are made from plates 1 1/16 in. thick for working pressures of from 160 to 350 lb. per sq. in. Owing to the fact that the boiler consists of a considerable number of small sections of nests of tubes, it is very flexible and will stand sudden variations in the load without any straining or injury. In proof of this I would refer to a boiler which has been designed for evaporating about 4,000 lb. of water per hour, and which has been worked up to 7,000 or 8,000 lb. per hour for the last six or seven years, and yet has stood the test, and is still at work. It is of course unwise to work a boiler in that way on continuous overload, and I have mentioned this instance merely to prove the suitability of this type of boiler for all conditions of work. I cannot agree with some of the author's remarks in connection with superheaters. For example, he states that if the superheater is placed in the hotter portion of the boiler the tubes become overheated and burn out, and there is difficulty in keeping the tubes in position. There is no doubt some justification in this contention. Superheaters should be designed and worked to meet the requirements, and then no trouble will be experienced even if they are placed in the hotter position as with Nesdrum boilers. They must be so designed that Mr Taylor the tubes nearest the inlet and outlet are always full of steam under all conditions; there is now no difficulty in arranging for this. There is no need to flood the superheater or to use mixing valves; both are a source of danger. For instance, if we suppose that the temperature in the front combustion chamber is 2,000° F. under normal conditions, and that when the boiler is forced the temperature will rise to 3,000° F., the result will be that as the temperature of the furnace rises the amount of steam passing through the superheater will increase so that the superheat will remain normal if the superheater is correctly designed for normal and full-load or overload conditions. It must be borne in mind that due to the position of the superheater in the front of the combustion chamber it is only exposed to the radiant heat, and is not in the direct path of the gases, so that it is not so liable to injury as a superheater placed behind the first row of water tubes.

The tendency of the steam to take the shortest passage or least line of resistance to the superheater outlet, thus causing the tubes nearest the inlet to suffer due to the lack of steam to fill the tubes at all times, can be easily overcome by compelling the steam to pass through all the tubes by fitting division plates in the superheater headers, thus dividing up the boxes in a suitable manner. We do not approve of flooding the tubes whilst raising steam, or mixing saturated steam with superheated steam to reduce the amount of superheat. I understand that the author also does not approve of this mixing arrangement owing to the danger of burning out the tubes. With regard to the inaccessibility of the modern superheater, its tendency to become choked up with soot, and the difficulty experienced in "sooting" the boiler itself due to the position of the superheater as shown in Fig. 2, all these objections disappear when the superheater is placed high up in front of the combustion chamber as in a Nesdrum boiler. It may be of interest to mention that we have recently quoted for a superheater in this district to withstand a final temperature of 900° F. I would also mention that superheaters are now constructed with cast-iron gills to protect the tubes for high superheat, etc. I refer to the Foster superheater as manufactured by Messrs. Heenan and Froude. In connection with the drop in pressure in modern superheaters we have experienced a drop of only 4 or 5 lb. at most. We have never experienced the slightest trouble with respect to varying water levels or corrosion in the steam space. I do not agree with the author's suggestion to raise the front drum of a boiler by about 12 in., for if the fireman allows the water level to fall owing to not being able to keep the pressure, and the stop valve is closed on that account, the water level in the front drum will drop still further and there will be serious danger of the lower side of the drums and the top ends of the tubes, where the greatest heat is, being bare of water. I agree with the author's remark about a high temperature being desirable in the boiler furnace. A large combustion chamber of a shape such as that in the Nesdrum boiler is necessary in order to obtain a high efficiency and prevent smoke. We have obtained from 85 to 87 per cent overall efficiency from such boilers fitted with superheaters and economizers.

Mr. P. S. THOMPSON: I think the author is very rash in Mr. Thompson. saying that at least eight of the leading makes of water-

npson. tube boilers would permit of steam being raised from cold water to the full working pressure in 30 minutes, although probably he has many a time had to do something like that in order to deal with sudden loads. I also do not think he can reconcile the position of the superheater given in Fig. 1 with present-day practice in boiler operation. I take it that the final temperature of the escaping gases would be about 460° F. If so, the superheat that he foreshadows would not be obtainable, otherwise the gases would have to be allowed to escape at a very uneconomical temperature. The two conditions seem to be somewhat paradoxical. I do not think it was the question of first cost so much as the demand for a high superheat that brought about the position of the superheater which he criticizes. The "sooting" problem has sometimes to be dealt with by removing a number of the tubes in order to give access to a man so that the soot can be satisfactorily removed. I should like the author to state if possible the amount of dust that is carried along with the flue gases from the low-grade fuel with which he has to deal. The dust question is most important, and has considerable bearing on the operation of boilers. The author says that the Navy could quite easily make use of bituminous coal. No doubt they could, but one of the essential points of the economical burning of such coal is, as he states, that there should be large combustion chambers. Would space permit of combustion chambers large enough to avoid smoking from the funnels? I do not agree that it is necessary to drain superheaters. I have some in mind that are rather complicated in form and which it is absolutely impossible to drain. They form part of the main steam pipe, and when the boiler is shut down the superheater of course gradually fills with condensed steam, the water re-evaporating when the boiler comes into commission. Mr. Taylor has mentioned a superheater that is placed just behind the front wall of a particular type of boiler. This seems to be quite all right as far as it goes, but where boilers are subject to a very variable supply of fuel, as in the case of blast-furnace gas, when the gas goes off the steam also goes off; there seems, however, to be sufficient radiant heat in the brickwork to raise the tubes to something like red heat. It seems to me that there is rather a danger of the tubes suffering, though Mr. Taylor says this does not affect them very greatly. I scarcely agree with the author in wishing to use water-tube boilers with less water, as he evidently intends to do owing to the raising of the front drum. One of the troubles with water-tube boilers is that there is not enough water reserve; it would be a pity to sacrifice any of that. The difficult question of priming should be treated on its merits, particular attention being given to the feed water supplied. I should be glad if the author could give us any figures as to the furnace temperatures necessary for very low-grade fuel, and also tell us something about the cost of cleaning the various types of boilers with which he is concerned.

Cowell. Mr. R. E. Cowell: The author appears to have definitely made up his mind that the vertical-tube boiler is the most favourable. There are, however, many boilers having horizontal tubes which are doing excellent work. Reference is made on page 476 to soot clogging up certain portions of the path of the gases and to tubes giving out. Does that occur locally where the gases are concentrated or the passage of the gases is obstructed? With regard to placing the superheater above the water-level, it is customary for consulting engineers to submit a plan and to ask for a quotation for a superheater in a certain space. Mr. Wright mentioned tubes with cast-iron gills. I fear that these would make up very quickly on the outside when firing with blast furnace gases, but I believe, as he says, that in the case of coal firing this superheater has proved very satisfactory on the Continent. A number of superheaters on the lines of those with which the author has had experience have been installed, some 14,500 integral superheaters and over 100 independently-fired superheaters being at work at the present time. The largest integral superheater has nearly 3,000 sq. ft. of heating surface, and is fitted to a boiler of over 8,000 sq. ft. heating surface supplied to the Kensington and Notting Hill Electric Lighting Company. The largest independently-fired superheater that has been supplied has 5,020 sq. ft. of heating surface. The tendency nowadays is to have very high superheat: on the Continent one frequently finds 700° F. The use of bituminous coal in the Navy introduces the question of mechanical stokers, which up to the present have not proved a success. The advent of oil firing, however, which is now almost universally adopted, has practically settled this question. With regard to water softening, has the author had any experience of the luminator process introduced a short time ago by the Westinghouse Brake Company? It may be of interest to mention that at West Ham small coal is being conveyed from the barges to the coal store on the same system as the ash-handling plant described by the author. No dust is made and a lot of labour is saved. Mr. Cowell.

Mr. W. McLeod: The high superheater temperatures that are desirable seem to me to be rather too much to ask for, because I think that with a temperature above, say, 550° F. the life of a superheater will not be very long. I can quite see that if such temperatures are desirable, something like the superheater described by Mr. Wright will have to be used. Of course the objection to such a type is the sooting up. If we can improve the combustion so that there will be very little deposit on the heating surfaces, we shall get a higher efficiency. I should like the author to tell us something more about surface combustion. Mr. McLeod.

Mr. A. Davidson: We have had excellent results from Stirling boilers, although we have not used them long enough to come to a definite conclusion. I think it is very necessary that economizers and boilers should be considered together. There seems to be a very great difference of opinion as to the correct size of economizers, and I should be glad if the author could refer to this in his reply. Mr. Davidson.

Mr. A. Stonehouse: The boilers that we have are fired with blast-furnace gas and waste gas from coke ovens. Mr. McLeod has remarked about the sooting or deposit of dust on the tubes, which is a great source of trouble. No doubt in years to come some system of dry cleaning the gas will be successfully adopted. In some cases the gas is being cleaned by washing; personally I do not think this is what is wanted. As to water-tube boilers, I agree with the author that the tubes should be vertical if possible. We find that with the large combustion chamber (I am referring now to gas-fired boilers) we are getting good results—far better than in previous Mr. Stonehouse.

. onehouse. years when we had no combustion chambers. Our Stirling and Woodeson water-tube boilers are fired with blast-furnace gas, whilst the Babcock boiler uses the waste gas from coke ovens. I think much better results would be obtained if we had more space among the tubes. I do not know whether it would be an advantage to have the high superheat that the author suggests, although the tendency is that way.

: Sarvent. Mr. J. F. Sarvent (*communicated*): Is it not a slight defect in the superheater as fitted to most Babcock boilers of the land type that the superheat decreases when the draught to a boiler is reduced? At light loads the superheat is not so high as when the boiler is steamed hard. Of course, with an independently fired superheater this does not occur, the tendency being for the superheat to increase with the diminished volume of steam passing. Another defect of the ordinary type of Babcock superheater is the process of flooding and draining. A superheater on a boiler evaporating about 25,000 lb. of water per hour takes some 15 to 20 minutes to drain. If such a boiler be required in an emergency it could not of course be put into service for the above period, provided that the steam pressure, etc., were correct. In the case of a boiler that is taken off on a Saturday afternoon and has to go into service again for the lighting load in the evening, would the superheater tubes suffer by allowing the superheater to remain unflooded for 5 or 6 hours so as to be ready for instant service if required? This defect is of course obviated by having a mixing valve fitted, so that saturated steam alone can be drawn off. Can the author give any information as to the height of the bridges in the furnace of a Lancashire boiler? I have noticed that the height of the bridges in different stations varies considerably, although the boilers may be the same size, burn similar fuel, and have about the same draught. It would seem that where the higher bridges are used there is greater economy in the use of fuel. Is this so, and what is the precise effect; has it a sort of throttling action on the air passing into the flue, or does it tend to more intimate mixing of the air and the fuel? The author states that we are on the eve of the adoption of very highly superheated steam. I take it that this remark applies purely to turbine-driven stations and is not a general statement. Due to the carbonization of the oil in the engine cylinders, the adoption of very high superheats would of course be impossible in stations where reciprocating sets are installed.

r. awson. Mr. T. A. Mawson (*communicated*): The system of removing ashes by pneumatic or hydraulic means seems to me very good. But might not another refinement of construction be added—I refer to an improved means of removing the dust from below the boiler tubes (in types like the Babcock boiler). Where there is a basement below the boiler-house floor I would suggest that a brick or concrete tube be provided, having its outlet door by the ash doors and communicating with the dust repository beneath the tubes. In addition to saving time this arrangement would allow of the dust being removed if necessary when the boiler was at a temperature too high for anybody to enter it. Again, there seems to be no reason why in the case of gas- or oil-fired boilers the feeding of gas (or oil), air, and water, could not be made almost entirely automatic, and in the case of coal-fired boilers semi-automatic.

Mr. J. W. Jackson (*in reply*): In reply to Mr. Turnbull, machine firing, although it appears to have been tried at sea in a more or less small way, is without doubt a very attractive scheme, and although possibly the chain-grate stoker is not the most suitable stoker for the work, there are plenty of other machines that would handle the varying grades of fuel fairly satisfactorily. There should be no difficulty whatever in the use of big coal, as coal crushers have been obtainable for some time and will crush the biggest and hardest coal in an entirely satisfactory manner at a very small cost per ton. Altogether the saving in labour to be effected in this direction, more especially on the bigger ships, will receive consideration in the near future. Mr. Jackson.

In reply to Mr. Baker, there should be no difficulty in obtaining a superheat of 700° F. with the superheater shown in Fig. 1 when it is remembered that this superheater is subjected to a gas temperature of about 1,200° to 1,400° F. This design of superheater does not appear to be influenced by the size of the boiler in any way, and it is located immediately alongside the main flue up-take.

Mr. Selvey's figures indicate that much lower temperatures can be used than is the present practice, thereby giving rise to considerable economies; it is from this point of view that the work of Professor Bone and of the late Dr. Nicholson is of such great value. With regard to rearranging economizers so that they work on the "contraflo" system, experiments have been made in this direction, and although the differences are not great they are, however, worth having. In any case it costs no more to have the economizer arranged on this system. So far as can be seen, "nut coal" can never be as cheap as "duff coal," but a considerable amount of duff coal of a high calorific value can be bought cheaply. Alterations have been made to stoker gears so as to allow the finest duff coal to be handled at a reasonable cost per ton, so much so as to make it worth using.

In reply to Mr. Baxter, the reason for the preference that certain engineers have for the Lancashire boiler cannot very well be given in the form of definite technical advantages for general steam-raising work. The large cylindrical type of boiler works against a serious disadvantage, and unless it is fitted with an economizer of great capacity it can never be worked economically. With reference to the type of turbine blading that is suitable for the highly superheated steam, unless turbines of enormous capacity are to be used, where the steam passages are large, the turbine will most probably be arranged for the first stage, at any rate on the Curtis system, and most probably the low-pressure part will consist of the simple re-action blading. There are, of course, refuse destructors that are unsatisfactory. On the other hand, this system has been given a lot of thought, and really satisfactory designs are now at work by which it is possible to consume almost any combustible material.

In reply to Mr. Clemitson, it is almost impossible to state a definite figure for the amount of steam that can safely be by-passed in the superheater by means of throttling the steam, since so many other things have to be taken into consideration. It seems to me that where the amount of superheat is to be controlled by means of a by-pass valve in the steam space, it is still more important that the superheater should not be placed in too hot a

Mr. Jackson. position; it should be as far away as possible from the boiler furnace. The reason that a superheater well removed from the furnace will give a more regular amount of superheat than one that is placed near the furnace is due to the fact that as the boiler capacity is decreased owing to the fouling of the water tubes the temperature of the gases rises. In the case of a superheater placed near the furnace, the fouling of the main water tubes also reduces the gas spaces between the tubes, and in effect causes a smaller draught in the furnace, thus allowing the temperature of the latter to rise higher than before. And having none or possibly only a few water tubes to pass, and seeing that the steam flowing to the superheater tubes is somewhat reduced, this causes the superheater in many designs to give a considerably increased steam temperature.

It is well known that the temperature rises in most chain-grate furnaces as the gas passages become fouled. There appear to be two main reasons for this, one being that the boiler is subject to a very low draught, and the other that the tubes being fouled with clinker do not take up the radiant heat from the furnace; this has therefore the effect of increasing the refractory lining of the furnace, thereby allowing the furnace temperature to rise. Under such conditions as these the furnace temperature will rise by as much as 1,000 degrees F., the same class of coal being used. It appears to be the general impression that the steam pressure is not likely to have to be considerably increased in the future. For steam turbines a pressure of 200 lb. per sq. in., or thereabouts, is the limit that is at present being used, and is fairly difficult to deal with; but the designers of steam turbines get a much greater economy by using superheated steam. The overall increase in efficiency of a boiler and turbine plant due to increasing the steam temperature is a very considerable item, and a steam temperature of 1,000° F. is by no means out of the question if suitable metals can be obtained for dealing with it.

The reason for suggesting that the front drum of the particular type of boiler should be elevated 12 in. above the back drum is to allow larger steam spaces than at present. Where there is any tendency to priming, most engineers will agree that it is necessary to carry as small an amount of water in the drum as is reasonably safe, thereby allowing the steam bubbles to become disengaged from the water with the least possible disturbance. These notes were written from the point of view that a man is employed to watch the level of the water in the drum and keep the levels constant, or that an automatic feed-water regulator be employed for the purpose. This apparatus promises well. It is possible to have very serious trouble from boiler corrosion where no trouble whatever is experienced with condensers; this especially applies where the make-up feed water may have a high percentage of magnesium chlorides and sulphates, etc.

As to covering the boiler brickwork with steel casing with a view to reducing the air leakage, this is a very valuable asset to a boiler of any make. Where modern boilers are so fitted it is important to see that the brickwork is kept in intimate contact with the steel casing. There should be no air space. If a passage is left, the gas will by-pass the main tubes of the boiler, thereby destroying the steel casing and allowing heat to be lost up the chimney. Mr. Jackson.

Mr. Vernier raised a very interesting train of thought in suggesting the use of the by-product recovery plant together with a gas producer. In order to supply the electrical energy for such a large power system as that in this neighbourhood a by-product recovery plant with a gas-producer plant would have to be of such enormous dimensions that the electrical generators would represent only a very small percentage of the total capital outlay for such an installation. The business of a company adopting such a scheme as this would appear to be that of a by-product recovery company rather than an electricity supply company. Mr. Vernier's remarks, however, cannot be dismissed with a few minutes' thought; they require a lot of consideration.

With reference to Mr. Wright's remarks regarding the Foster superheater, it is a type to which I have not given much attention up to now. It certainly seems to have several important advantages, and to be protected against high temperatures. I am a little afraid that the introduction of the gills on the tubes may create collecting spaces for the dust, from which unfortunately we do not seem able to get away. Dust may completely insulate the tubes, and they would then become inoperative as a superheater. With regard to the question of the drop in pressure across the superheater, the figures that I have quoted are actual measurements by pressure gauges, and there is no doubt about their being correct. A number of gauges were used; they were all interchangeable and all subjected to a pressure test afterwards.

With regard to Mr. Wright's point as to the air supply to the boiler, I think the best guide we can have to this is the amount of CO_2 in the outlet gases. If the amount of CO_2 in these gases is correct, the air supply to the furnace is also correct, and there will be no difficulty in that respect. First of all, I assumed that the modern furnace is the furnace under discussion; that means a furnace of ample capacity and size. That being so, we can assume that the furnace will require most of the air that gets there. As to the amount of CO_2 that should be aimed at in good practice, generally about 10 to 12 per cent of CO_2 at the outlet of the boiler appears to be the maximum that can be carried. That seems rather a low figure—low compared with what some manufacturers of stoker gear expect, namely, 14 to 15 per cent. It is quite probable that if this latter percentage of CO_2 were carried the furnace brickwork would collapse very quickly. The furnace brickwork is the controlling factor. We may only have 8 per cent of CO_2 in the boiler outlet and 14 per cent under the boiler arches. It is often difficult to ascertain where the leakage occurs—whether in the furnace or at some point between the furnace and the outlet. If a leakage does occur it must be located and dealt with without delay if a high efficiency is desired. It seems to me that the point is met. That is to say, if one aims at an average of about 12 per cent of CO_2 in the furnace, and allows this to fall to something like 10 per cent, no very serious damage can be done to the furnace anywhere, and a fairly efficient combustion is guaranteed.

Mr. Wright asks about a flat arch in preference to the cambered arch. For reasons of efficiency we all aim at

Mr. Jackson. obtaining the highest possible percentage of CO_2 in the furnace. The firebrick will only stand a certain temperature before it collapses: for continuous working that temperature is generally between 2,500 and 3,000° F. As a temperature of 3,000° F. is approached, corresponding to 12 per cent of CO_2, the firebrick usually becomes quite soft; if the furnace arches were flat they would therefore collapse at a lower temperature than if built with a fairly big camber, *i.e.* with a small radius.

A large number of water-cooled ash stoppers have been introduced by the leading makers, but none has worked satisfactorily, the reason being that the ash-stopper has got choked with scale from the water that has been used for cooling. Some engineers recommend the use of distilled water. Even when that is done, owing to the violent changes of temperature that occur, the greatest difficulty is experienced in keeping the pipe joints tight. Dumping bars of very heavy section allow heat to be transmitted quite readily to the more protected parts, and solve the difficulty without water cooling.

I am pleased to hear that it is possible to dish the drum ends of the Nesdrum boiler without serious straining. I have never heard of any troubles developing with those drums, but I have known of many cases of boiler drums failing where the dishing was no more acute than it appears to be in the case of the Nesdrum boiler. This is a point that will have to be watched very closely indeed, since this dishing allows local working and straining to take place. The particular boilers to which I refer have drums of greater diameter than those mentioned by Mr. Taylor. He also referred to the overloading of boilers. I do not think it is possible to overload a boiler provided the temperature can be taken up in an efficient manner before the back end of the boiler is reached; but if the temperature of the gases is reduced to the lowest possible point, *i.e.* about 100° F. above the temperature of the steam, then the boiler can be overloaded.

I do not agree with the position chosen by Mr. Taylor for the superheater used with his boiler. It will probably get filled up with dust owing to the eddies set up in that position. The dust is given off in at least two forms. One leaves the furnace as a solid, and the other passes off from the fire in the form of vapour, which condenses again as the temperature is reduced. This latter is the dust that blankets every surface so completely. It settles around the tubes very closely and is not easily blown off. A steam jet or an air jet has to be applied very closely indeed to remove it.

With regard to the corrosion of the superheater (Fig. 3), I know of boilers which have failed in the manner pointed out. In all cases the superheater tube was choked with solid matter, thus allowing violent corrosion to take place internally as well as externally, due to excessive heating and to magnesia and lime scale being deposited in the tubes. I know of another design of superheater where scores of tubes are being replaced; they are not bent, but straight tubes. It is not due so much to choking up as to wet steam given off by the boiler passing direct to the superheater tubes.

With regard to the water level in the drums, my point is that if the drums are left in their existing positions with regard to the water level, the steam space in the main drum is relatively reduced. The front drum collects between 60 and 80 per cent of the total steam, and the steam space is reduced owing to the relative size of the water space being increased. That being the case, priming takes place more readily than it would otherwise do. My remarks were the result of experience in the matter. I should like to add that I do not think we have sufficient space for the deposition of spray in the water-tube boiler. The water ought to be deposited more readily than it is. Mr. Jackson

Mr. Thompson mentioned the quick raising of steam. I have on a few occasions seen boilers heated quickly, and they stood the test perfectly satisfactorily. The boilers were afterwards hydraulically tested to a pressure 50 per cent higher than the working pressure, and were found not to have suffered in the slightest degree. This is one of the main reasons why a water-tube boiler is to be preferred to a cylindrical boiler. The latter can only be heated very slowly. I should like to explain by referring to Fig. 1 how it is that the superheater will take up the high temperature without allowing the high temperature gases to escape to the chimney. The gases rise through that section of the boiler that is farthest removed from the steam drum, come down through the superheater through the middle section of the boiler, turn round again and rise immediately behind the steam drum up to the flue. The flue is indicated at the position of the butterfly damper. This particular superheater is subjected to a gas temperature of about 1,400° F. when working at normal load. I believe that temperature is sufficient to give us the whole of the superheat that would be likely to be required, *i.e.* 900° F.

The large amount of dust from low-grade fuels is very difficult to deal with, especially with the lower grade of fuels. Unless the temperature of the furnace is kept high a considerable amount of dust escapes. There is some difficulty in keeping a high temperature in the furnace, since the air to the furnace must to some extent be cut down to the minimum so as to make the amount of the CO_2 as high as possible; that is to say, the furnace temperature cannot be kept up by using an excess of air. I have seen boilers fired with coal picked up from the waste heaps from the countryside in the form of duff, all of it so small as to pass through a $\frac{1}{4}$-in. mesh, and with a heating value of only 8,000 to 9,000 B.Th.U.'s per lb. There was very little dust from the plant, because the temperature was allowed to rise so high that dust was thrown on to the back wall of the furnace as molten slag. The boilers were kept on load for several weeks at a time without any difficulty, the temperature not being high enough to cause a breakdown of the brickwork.

Considering the superheater again, I have mentioned that the temperature of the gases impinging on the superheater in Fig. 1 is 1,400° F. I have on several occasions seen cases where the air supply to the furnace has been kept low enough to allow combustion to be again set up in the superheater space. That is to say, the amount of CO_2 in the furnace was about 16 or 17 per cent. There was a little leakage into the boiler space between the first pass of the main tubes and the superheater. I think that is one reason for the fire issuing from the chimneys of ships. The combustion chamber is also sometimes too small to allow combustion to be completed. I have seen many experiments in connection with furnace temperatures. With the amount of CO_2 under the arches at about 12 per cent— the temperature under the arches would be of the order of

Mr. Jackson. 3,000° F.—and with the back end of the boiler kept reasonably tight, that temperature would be applied to the furnace tubes without any appreciable drop. Immediately the second row of tubes is passed (Fig. 1 will illustrate the point) there is a drop of as much as 1,000° F. across the first two rows of tubes. The interesting point is that the first two rows cause a considerable drop in the temperature. In the case of the boiler in Fig. 4 the front portion of the first section of the tubes carries the correspondingly heavy duty. These tubes cause the temperature to fall about 1,000° F. The front section performs between 65 and 75 per cent of the total work of the boiler.

Mr. Cowell raises a very interesting point in regard to the advantages and otherwise of a vertical or nearly vertical tube as against a horizontal tube. Both have their advantages. The reason why I really prefer the vertical-tube boiler is that I believe it allows a larger circulation; it therefore more readily takes up the heat that is transmitted to the tube, and for equal heating surfaces gives a higher evaporative efficiency. Also, because of this violent circulation, it does not hold the mud that is deposited in the boiler so readily as does the horizontal-tube boiler. In the case of the nearly horizontal-tube boiler the steam is undoubtedly superheated; this is an undoubted advantage.

I have figures to show that the steam is superheated by as much as 20 degrees F. in the steam drum of a horizontal-tube boiler, and this superheating takes care of any priming that may have occurred in a superheater such as that in Fig. 1. Under these conditions corrosion of the superheater does not take place. The designer of vertical-tube boilers must therefore arrange so that the steam is disengaged without causing any priming; and if he can secure this slight degree of superheat in the main and generating tubes so much the better.

With reference to the corrosion of the interior of the tubes, all the corrosion that I have seen has been local, due to this comparative priming, and in that case the corrosion occurs on the ends of the tube and for the first few inches only: it does not get beyond that point. Where the tube is bent, and suspended in the vertical position, as in Fig. 3, this corrosion occurs inside and outside the tube at the bottom of the bend, the tube having become choked with boiler mud and corrosion. The mud gets wet when the boiler is off load, and when subjected to the higher temperature chemical action sets in, causing further corrosion as well as excessive heating. The tubes of which I have known increased in diameter before they finally burst. The normal diameter being $1\frac{1}{2}$ in., the metal stretched to 4 in. before bursting.

With regard to the temperature of the superheated steam, any degree of superheat desired can be obtained with the arrangement shown in Fig. 1 without any difficulty. I should have shown a more complete arrangement of the by-pass damper. Between the two top tubes and the main generating tubes a by-pass damper is fitted. That damper can be opened as far as is found desirable, therefore completely controlling the superheater.

I have had no experience of the luminator process. I know, however, of one case where it had no effect on the boiler water, but affected very considerably the condenser water. Where hydrochloric acid had previously to be used to remove scale, the luminator kept the scale soft Mr. Jackson. enough to allow of its being removed by a good strong brush. I have heard from boiler inspectors and officials very favourable reports of the luminator plant. Before the luminator plant was installed the boilers had to be taken off load every three weeks and thoroughly scaled—the scale was very thick by that time—but with the luminator installed they were able to run the boiler for 13 weeks without any trouble. This boiler was opened up and found to be quite clean. It was run for a further three months and was still found to be quite clean. All their boilers are now running on luminator plant and are quite clean. It prevents the soft matter from forming scale and causes it to be deposited in the form of mud. I understand that the luminator will not work at all in some districts, mainly where chlorides are found in the water; that is the main disadvantage. It has been clearly demonstrated that the action is purely mechanical: there is no chemical change whatever. On the other hand, it is stated that the aluminium is dissolved from the plate, gathers round the molecules as they settle out of the water, and covers them with a slippery coating so that they cannot adhere together.

With regard to Mr. McLeod's request, I regret I have had no direct experience with either of those boilers. As I pointed out, the Bonecourt boiler has a somewhat limited field, and when it is coal-fired I think it can never be as efficient as a coal-fired boiler, since where coal is used for fuel a gas producer is necessary, the increased efficiency of the Bonecourt boiler being counteracted by losses in the gas producer. There is a lot of investigation work being carried out on gas-producer schemes and the recovery of by-products. The gas-producer scheme is more or less a failure where used purely for gas firing under a boiler.

Mr. Davidson asked about economizers; as a rough guess I think every boiler should be supplied with an economizer having not less than one-quarter of the heating surface of the boiler. That is a big economizer, but these are very much in fashion to-day. They are much safer to work with in all respects, and permit of a high evaporative efficiency being obtained easily under ordinary service conditions.

In a communication from Mr. J. F. Sarvent stress is laid upon the necessity of draining the superheater of the ordinary land-type steam boiler, it being pointed out that, no matter how great the emergency may be, the superheater, which is normally situated underneath the main steam drums, cannot be drained in anything less than 15 to 20 minutes. This is a very serious objection to this type of superheater. Highly superheated steam, such as may be expected in the future, is of course only suitable for turbines, and therefore these remarks apply to such stations.

In reply to Mr. Mawson, as stated earlier in this reply feed-water regulators have been at work for some time, and are regulating the water level in a most satisfactory manner. There are, of course, conditions where automatic regulators are quite unsuitable, and in installing a regulator consideration must be given to the feed pump. If the feed pump is of a reciprocating type it must also be controlled automatically, but if of a centrifugal type controlled by water pressure it need not be specially controlled in order to make automatic feed-water regulating a complete success.

DISCUSSION ON

"ELECTRIC LOCOMOTIVES." *

BEFORE THE INSTITUTION, 26TH FEBRUARY, 1914.

Lydall. Mr. F. LYDALL (*communicated reply*): Mr. Roger Smith has drawn attention to the suggestion for a goods locomotive on page 746 of Volume 51, namely that in which an equipment is provided capable of exerting a tractive effort of about 12 tons at 25 miles per hour, and has remarked that if such an equipment included continuous-current series-wound motors the maximum starting pull would be something like 30 tons. I quite admit that such an equipment would be a departure from the ordinary practice, and I only made the suggestion because it is not self-evident that the usual practice of running traction motors in such a way that their maximum output is only developed at speeds much below the steady running speed of the train, is necessarily the best course to pursue in dealing with the haulage of goods trains. I venture to think that there are no technical difficulties in the way of such an equipment as I have suggested, and I pointed out that it is for the railway engineer to decide whether the advantages of running at relatively high speeds up the gradients are sufficient to warrant a somewhat expensive equipment on the locomotive.

The control apparatus of such an equipment must of course be suitable, and the tractive effort exerted by the motors must not be allowed to exceed the proper value as determined by the strength of the draw-bar, although, of course, continuous-current motors could do so without difficulty. With series, series-parallel, and parallel control, combined if necessary with field control, I believe the speed regulation of such a locomotive would prove all that could reasonably be desired without making it necessary to run on the resistances. In the case of single-phase motors speed control is naturally a very simple matter, as indicated in the paper on "Motor and Control Equipments for Electric Locomotives."

In this connection I may perhaps refer to a doubt expressed on a previous occasion by Mr. Roger Smith with regard to the express passenger electric locomotive suggested on page 747 of Volume 51, more particularly in respect of the tractive effort at 75 miles per hour, viz. 8,000 lb. While he is, I believe, perfectly correct in saying that no such electric locomotive has yet been built, I think a reference to the table of locomotive motors on page 397 of Volume 52 will convince him that, given the demand for such a locomotive, no difficulty will be experienced in meeting the demand and in providing a locomotive capable of meeting all the requirements suggested. For example, suppose the continuous rating of the motor equipment is taken at 1,900 h.p., corresponding to a tractive effort of 12,000 lb. at 60 miles per hour, the last motor in the table, viz. W.B.M. 3,700 s. may be referred to. This motor has a continuous rating of 769 kw. input; that is about 950 h.p. output. A pair of these motors would clearly meet all the requirements of the case, provided the proper wheel diameter be chosen to give the required speed at the continuous rating. The pair of motors would weigh 26·8 tons, exclusive of motor Mr. Lydall. shafts, bearings, etc., which cannot be regarded as excessive for a locomotive with three driving axles and a leading trailing bogie. With continuous-current motors the weight would probably be less.

Mr. Roger Smith's remark that if such a locomotive could be built and put into service, the working conditions of passenger traffic would be greatly altered, leads one to hope that such an experiment will be made in order to ascertain the effect of the change in conditions. It would obviously be a simple matter to effect a general speeding up of the long-distance passenger service, especially on lines where there are many gradients, and this could be done without in any way exceeding the speed limits at present in vogue, but simply by maintaining a high speed up the gradients where now the best that can be done with steam locomotives is from 30 to 40 miles per hour. Such a modification would not create any difficulties due to lengthening existing blocks. It is, however, for the electrical engineer to bring to the notice of the railway engineer the possibility and practicability of constructing such locomotives, and then to leave to the railway engineer the task of deciding whether such locomotives can be profitably employed.

The figures for tractive resistances of the locomotives assumed in the paper have been questioned. Mr. Roger Smith considers that a difference of 700 lb. between tractive effort and draw-bar pull at speeds of 25 to 30 miles per hour is insufficient. Perhaps I may refer to the tests on the 1—C—1 locomotive equipped by Messrs. Ganz & Co. for the Valtellina Railway, described in the *Revue Generale des Chemins de fer* for March, 1905. The results of a number of tests are given in the form of a curve, from which the following points may be taken :—

Speed. km. per hour	Tractive Resistance. kg. per ton
25	2·3
40	3·5
60	5·5

These figures refer to the locomotive alone, and show that it is reasonable to take much lower values for electric than for steam locomotives. The figure of 700 lb., which is equivalent to about 10 lb. per ton, is well above the value mentioned above, viz. 3·5 kg. per ton.

I think Mr. Roger Smith has misunderstood the remarks in the paper dealing with the combination of gearing and coupling rods. I tried to show that the use of geared motors for locomotives intended for high speeds led to uncomfortably high gear velocities, and in doing so I argued the case for several alternative methods of using geared motors, among others large motors geared to jack shafts, these shafts being coupled by side rods to two or more driving axles. I had no intention of going beyond this argument. Such a method may be quite a good solution of a difficulty, if the conditions do not lead to

* Papers by Mr. F. Lydall (see pp. 381 and 384, and vol. 51, p. 739).

Mr. Lydall. excessive gear velocities; and, as hinted at in the Supplementary Paper, it may even be worth while to make special provision for dealing with abnormal gear velocities in cases in which they are unavoidable.

I am not aware that any other difficulties have been experienced with induction regulators for single-phase locomotive equipments, apart from that mentioned in the paper. I am sorry that I am not in a position to give any information as to the working of electric locomotives on steep gradients and how the question of starting on such gradients is affected by the type of control.

Mr. Carter has evidently misunderstood the purpose of the paper on Electric Locomotives. This purpose is stated in the second paragraph on page 740 (Volume 51), viz. "to refer to certain considerations which in my opinion must be taken into account in settling the design of a locomotive to meet a set of specified conditions." The list of locomotives contained in Part I is intended for purposes of reference.

I will, however, try and meet Mr. Carter on his own ground. First of all, I must draw his attention to the fact that the paper in Volume 51 was completed just about the end of 1912, whereas the quotation that he gives from the *Electric Journal* is dated October, 1913. In the second place, I am convinced that it is better to abstain from criticism unless one is in possession of all the facts of the case. A certain amount of hearsay evidence mixed up with preconceived ideas based on theory is not enough to justify statements that one type has been a failure and other types are bound to be failures. I maintain that what is necessary to enable anybody to form a considered judgment is first a knowledge of the reasons that have brought any particular locomotive or type of locomotive into existence; second, a knowledge of the actual behaviour of the locomotive in question; and, third, if there have been any difficulties, a knowledge of whether these have been due to causes beyond ordinary control, such as collisions, etc., or to trifling causes easily avoided in future, or to some reason inherent in the design.

I am not convinced that either Mr. Carter or the authority that he quotes possess this requisite knowledge.

To deal more specifically with the instances given by Mr. Carter, he mentions that many of the types that I have enumerated have given trouble, and quotes first the experimental 1—C—1 single-phase locomotive for the Wiesenthal Railway. Mr. Carter says that this type is always recognized as one that will give rise to "nosing." He does not definitely state, however, that it has been subject to this complaint, nor do I gather that Messrs. Storer and Eaton say so. As a matter of fact, the makers of the locomotive who have watched its running for several years, have not found any tendency towards nosing. The locomotive is in regular service on the Wiesenthal Railway and there is no intention of withdrawing it or altering it.

Mr. Carter's remark that "the remaining nine locomotives are being built to a slightly modified design" is simply a manufacturer's way of expressing that the first locomotive is a failure, shows that he is entirely ignorant of the facts of the case.

Turning next to the extract from Mr. Hellmund's article on the "Electrification of Trunk Lines in Europe," the breakage of the crank pin on the 2—B—1 locomotive is referred to on page 762 of Volume 51, and the reason for the breakage is explained. Reference is made to the locomotives of the 0—D—0 type which "have so far given best satisfaction in service, although they are subject to rather pronounced vibrations." The statement that some type of geared locomotive would have been a better solution for this service, may or may not be true, but the reasons for this opinion are not given. Mr. Lydall.

As to the breakage in the third case mentioned, I have no information, unless the locomotive in question was one of those built for the Wiesenthal Railway and referred to in the Supplementary Paper.

Mr. Carter then puts forward his view of the fundamental cause of the troubles to which he has alluded namely, that "the uniform torque of a motor can only be converted into a pair of reciprocating forces in the direction of the side rods by subjecting the frame of the locomotive to very severe stresses." It seems to be Mr. Carter's opinion that these stresses have either been overlooked or insufficiently appreciated by the designers of the mechanical portions of the Continental locomotives. This is not the case, as a study of the technical Press on the Continent would easily prove.

When Mr. Carter states that the reason which he puts forward is sufficient to proclaim the side-rod type of locomotive as a type to be avoided wherever possible, his opinion is not borne out by facts. For example, he remarks that the difficulties due to this cause are greatest in that case in which the angle between the connecting rod and the side rods is a right angle. This is the case with the 2—B—1 locomotive on the Dessau–Bitterfeld line. As a matter of fact, apart from the breakage of the crank pin referred to on page 762 of Volume 51, the 2—B—1 locomotive equipped by Messrs. Siemens Schuckert has run very satisfactorily indeed for three years, and there is no reason why it should not continue to give satisfaction in future. It is highly necessary, therefore, to receive these theoretical propositions and the deductions from them with caution.

Incidentally I may point out to Mr. Carter that for full-gauge main-line locomotives the radius of the crank is not of the order of 8 in., but is usually from 12 to 13 in. The figures of torque and stress calculated by Mr. Carter therefore need revision.

Replying to Mr. Bowden, I do not know of any case in which motor-generator control has been employed in electric locomotives.

The opening remarks by Dr. S. P. Smith have, I think, been fully answered above. In regard to the comparison between the Pennsylvania locomotive motor and the 800-h.p. single-phase motor, it may be that Dr. Smith has access to information which I was unable to obtain. When, however, he asserts that the Pennsylvania motor, if designed for 1,200 or 2,400 volts would weigh much more than it does at present, he is indulging in prophecy, since no such motor has been actually constructed.

Personally, I agree entirely with Mr. O'Brien with regard to the advisability of providing for the driver in an electric locomotive a free look-out all round; but unfortunately this is not always possible, more particularly in those cases in which a large step-down transformer is required.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF THE 12TH MARCH, 1914.

Proceedings of the 564th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 12th March, 1914—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 26th February, 1914, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

Messrs. C. F. B. Marshall and A. H. Allen were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Members.

Bille, Harald.
Feldmann, Oswald.

Associate Members.

Fuller, William Payne.
Jennison, Matt.
Tasker, John Herbert.

Graduates.

Allington, Ernest.
Browne, Walter Stephen.
Fernando, Peter Charles.
Hollinrake, John Slater.
Phillips, Walter.
Willians, Willian Ratcliffe.

Students.

Broadwood, Leopold Alfred T.
Burke, George Bernard.
Burrage, Charles James.
Cam, Alan Noel.
Caspar, Frank Albert Emile.
Cheshire, James.
Croft, Edward Hugh.
Cuerden, Harold Seymour.
Delanoy, M. Lee.
Dixon, Fred.
Dobie, Percy.
Furnival, John Megarry.
Harrison, Roger William.
Lawrence, Frederick Charles.
Norburn, William Henry Joseph.
Norris, Eric Douglas Tobias.
Nyman, Alexander.
Porter, Henry Percy.
Poynter, Hubert Gorringe.
Sinclair, William.
Smith, Lewis Charles Reginald.
Smith, William Balfour.
Symons, Ernest John.
Tolley, Claude Edmund.
Trippe, Sydney Howard.

TRANSFERS.

Associate Member to Member.

Hunter, Philip Vassar.

Student to Associate Member.

Timmis, Arthur Carlyle.
Watkins, Stanley Sylvester A., B.Sc.

Student to Graduate.

Mansell, Laurence Thomas George.

Donations to the *Library* were announced as having been received from Messrs. Alabaster, Gatehouse & Co., The Chartered Institute of Patent Agents, W. Cramp, Sir John Gavey, C.B., The International Electrotechnical Commission, H. R. Kempe, P. D. Leake, Liverpool Corporation Tramways, Manchester Chamber of Commerce, Physikalische Technische Reichsanstalt, The Radcliffe Library, Professor D. Robertson, D.Sc. ; and to the *Museum* from Messrs. Edison & Swan United Electric Light Company, Ltd., K. Hedges, and H. C. Levis, to whom the thanks of the meeting were duly accorded.

A paper by Mr. H. E. O'Brien, Associate Member, entitled "The Design of Rolling Stock for Electric Railways" (see page 445), was read and discussed, and the meeting adjourned at 10 p.m.

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DISCUSSION ON "ELECTRIC BATTERY VEHICLES."

BEFORE THE INSTITUTION, 19TH MARCH, 1914.

Introductory Notes by F. AYTON, Member.

The importance to the central station of the load to be obtained by a general use of electric vehicles can hardly be over-rated. It is in practically all cases an "off-peak" load; and as it will in nearly all cases come on during the night, when the majority of the other consumers have ceased to make any demand on the supply, it will have a tendency to flatten out the generating station load curve in a most favourable manner. Every central-station engineer knows the beneficial effect that such an improvement in the station load factor will have upon the cost of generation, rendering it possible to reduce the selling price to all consumers, and, by the increased demand thereby created, greatly benefiting the electrical industry generally. Little wonder, therefore, that the central-station engineer, now fully appreciating these possibilities, is keen on doing all that he can to popularize the electric vehicle and to facilitate its adoption. The natural outcome of this keenness was the formation, by the Incorporated Municipal Electrical Association, of the Electric Vehicle Committee. The object of this Committee is to promote the adoption and use of the electric vehicle for business and pleasure purposes, and its constitution is framed on co-operative lines. The majority of its members are outside the Incorporated Municipal Electrical Association and consist of representatives of the electric manufacturing interests, the electric power companies, the electric vehicle manufacturers and agents, and others.

At the moment, the most promising opening for the electric vehicle appears to lie in its use for commercial purposes; but it is by no means improbable that the passenger-carrying vehicle, whether for business or pleasure purposes, will eventually be considered from the central-station point of view almost as important as the commercial type of vehicle.

One frequently meets people—some of whom, unfortunately, are engineers—who, at the mere mention of an electrically-driven vehicle deriving its energy from a storage battery, grow sceptical, openly expressing their doubts as to the possibility of such a method of road traction ever proving commercially successful. They apparently base their opinions upon the failures of past years. It cannot be too strongly emphasized, however, that the electric vehicle of to-day is not to be judged by the experiences of even a few years ago in this country. Since that time great advances have been made in storage battery construction, the design of the motors for electric vehicles has been improved, ball and roller bearings have been brought to a high pitch of perfection, chassis construction has been lightened, and better and more efficient rubber tyres can be obtained. For the improvements in the latter three items, the electric vehicle owes much to the wonderful evolution of the petrol car in the past few years.

The proper sphere of utility for the electric vehicle at the present time is undoubtedly in interurban and suburban districts where its mileage limit per charge is not a drawback. The passenger-carrying vehicles and the lighter pattern of commercial vehicles are generally capable of doing from 50 to 60 miles per charge, and it will be found that in most cases this covers the daily requirements for work in such districts as those mentioned. By a boosting charge during the driver's dinner-hour, the daily mileage capacity may be appreciably increased.

The utility of the electric vehicle in interurban and suburban areas is amply demonstrated by the number of vehicles in daily use in the United States alone. At the present time there are over 37,000 electric vehicles in use in that country, of which more than half are passenger-carrying machines used for business or pleasure purposes. There are said to be about 40 firms engaged in constructing these vehicles in America, and the number of such vehicles is increasing at a rapid rate. In certain cities on the European Continent, also, this type of automobile is rapidly coming into general use, and hundreds are already running and giving satisfactory and economical service.

If we have to admit that there are limits to the scope of usefulness of the electric vehicle; if we have to concede to the petrol vehicle, as we certainly must, some of the merits that it is known to possess; if we must agree that there are certain fields that the latter will probably continue for some time to hold as pre-eminently its own; it is nevertheless true that within its own legitimate sphere the electric vehicle can show a degree of economy, and a record for reliability, with which no other existing type of vehicle can hope to compete. We shall, I think, be wise if we frankly admit the probability that each type of vehicle will have its own distinctive field of use in which it will prove, on the score of suitability and economy, practically unassailable.

In spite of the fact that it has to provide and maintain its own roadway, and that this accounts for by far the greater part of the total capital expenditure, the average cost of operating electric tramcars in this country indicates that this method of transit is still the cheapest where the traffic to be catered for warrants the outlay. The trolley omnibus, again, has proved a cheaper means of conveyance than the petrol omnibus, in spite of having to bear the additional capital charges of the trolley line and feeders. Both these examples are only instances, out of many, showing that when electric driving can be suitably applied and combined with the supply of electrical energy from a central station, the results as regards convenience, economy, and reliability, are incomparably superior to those of the small independent power plant.

The electric battery vehicle is only another instance of the same kind. It also draws its energy from the central station—not continuously, I agree; but it is able to take it at times which are very convenient to the supplier, and under conditions that properly allow of a low price per unit being charged. There is certainly a loss in charging and storage, but in comparison with the electric tramcar and the trolley omnibus, this loss can to some extent be set off against the loss in transmission in the case of the two latter systems.

I think that these analogies, together with the well-known simplicity of the electric vehicle, its freedom from vibration, and the consequent lessened wear and tear, will go far to explain and make clear to the layman the reason why it proves in actual service to be so economical and reliable.

It is in the displacement of the horse that the real economic future of the electric vehicle lies. For haulage purposes in cities and large towns the days of the horse are numbered. The congested state of our thoroughfares demands his removal, and upon the basis of operating costs the electric vehicle is the only type of power-driven machine that can take his place. The relief of the traffic congestion in the main streets of our large cities and towns is well known to be an acute and pressing question. There is naturally a limit to the number of vehicles that can be accommodated in any street; and in very many cases that limit has already been reached. What is to be done? A general widening of main thoroughfares is economically out of the question. More efficient use must be made of the present street area. One obvious method of obtaining relief, then, is to bar horse haulage entirely. A pair of horses and a large van take up nearly double the street area required for an average motor vehicle of the same capacity, and for equal carrying capacity the electric vehicle, by reason of the simplicity and compactness of its mechanism, takes up the least space of any.

Considerable further relief of the congestion would follow from the fact that a good commercial motor vehicle can do in the same time more than twice the amount of work of two double-horse teams in city service. If we consider for a moment the serious delays that are at present taking place in the delivery of merchandise in our cities, and also the cost of these delays, which ultimately resolves itself into a tax upon the consumer, we can easily realize the immense saving that would accrue to the business community by the wholesale adoption of motor transport for city service.

But the already extensive adoption of the petrol type of commercial vehicle for this purpose has brought in its train conditions which, I suppose, everybody will agree have not added to the amenities of city life. The noise and smell from that class of vehicle have frequently been the cause of bitter complaint. Both these disagreeable features are of course absent from the electric vehicle, and for this reason alone it should assuredly commend itself for universal adoption in large cities and towns. It is noteworthy, in connection with what I have just said, that one of the leading engineering journals, when recently discussing the noise made by motor traffic and the means for preventing it, said: "Electrically-driven vehicles we do not propose to discuss as they are beyond criticism—at any rate, in contrast with other motor vehicles."

The position of the electric vehicle can hardly be considered apart from methods of charging its battery. With the batteries at present fitted, the impressed voltage required towards the end of the charge is in the neighbourhood of 110 to 120 volts. Since the supply pressures in use are generally above 200 volts, it follows that in most cases the charging must be done through the medium of some pressure-reducing apparatus. If the use of the electric vehicle is to reach the proportions that we so ardently desire, it is essential that the charging operation should be made as simple as possible; in fact, it should be made—as it can be made—practically automatic. It therefore remains for the central-station authorities and the manufacturers to see that reliable automatic apparatus is provided. It should be so constructed that when the correct terminal voltage for the whole battery (which is a good approximate indication of the battery's condition) has been reached, the motor-generator is automatically shut down. It is of great importance that vehicles should be able to run into any place where charging facilities are provided, and get connected up with ease. This points to the necessity of standard charging receptacles and plugs. The Electric Vehicle Committee, realizing the importance of this, have decided after careful consideration to recommend to the British Engineering Standards Committee the desirability of adopting the 150-ampere plug and receptacle of the Electric Vehicle Association of America as the standard fitting for this country. The American Association has standardized upon two sizes, 50 amperes and 150 amperes, but we came to the conclusion that, as the larger size would be required for most vehicles, it was desirable to keep to that alone.

I propose to conclude these very general remarks by touching upon the work that is necessary in order to bring

the uses and advantages of the electric vehicle before the general public. At the outset I would say that in my opinion we cannot look for much assistance at the present time from existing motor traders and garage proprietors. They are in possession of an established business in connection with the petrol vehicle, at which no doubt they are making good profits. They do not want that business interfered with, and they may have grave doubts as to the utility of the electric vehicle. As to its mechanism, its merits, and its economy, they are profoundly ignorant. They will only wake up to its possibilities when they see a created business around them and find a reduction in the sales of the petrol vehicle. In the meantime, then, the pioneer work has to be done, and it behoves the electricity supply authorities, as those who are going to benefit most by the extension of the use of the electric vehicle, to work hand in hand with the manufacturers and to carry on an active propaganda for advertising the electric vehicle.

We have got to educate the public and also those in charge of garages. We must show them that because the vehicle is electric it is by no means complicated ; in fact, it is by far the simplest and most sturdily constructed power-propelled vehicle at present on the road. We must advertise all its other good qualities, its ease of driving, its all-round economy, and its reliability.

I believe that the story of electric vehicle progress in Great Britain, as it will be told a few years hence, will be such as to constitute a complete rebuke to present-day sceptics. I believe it will be a story of splendid progress, a record of fine achievement.

[Mr. Beauchamp.] Mr. J. W. Beauchamp : In my district at the present time there are six vehicles which are being regularly charged from the public electricity supply mains, and I have good reason to think that this fleet will be doubled in the course of a few months. So far as I can estimate, the average revenue obtainable where electrical energy is sold at 1d. per unit will be something like £20 per vehicle per annum. In considering the estimates put forward of the cost per mile for running such vehicles, it must be borne in mind that the mileage varies with the requirements of the users of the vehicles, many of whom I find by the nature of their business are unable to obtain the full possible mileage of the vehicles. At the present time we are charging 1d. per unit for energy supplied for this purpose, and there is an alternative tariff by which a small fixed charge, based upon tonnage, is made per vehicle, with an additional rate of ¾d. per unit. This tariff was devised in order to meet the case of vehicles brought in for small boosting charges. In these cases the value of the charge to the consumer is considerable, whilst the amount of electrical energy taken may be so small that on the ordinary flat-rate basis it would not pay to receive and connect up the vehicle. The aspect of the electric vehicle business which appeals to me most strongly is that of "selling and general organization." At the present time four or five different types of vehicle are available on the English market, and so far as I can see these different types are for all practical purposes equally satisfactory, the difference between them being so small that one can recommend any type and be certain that the purchaser will obtain satisfactory results. The real difficulty at the present moment consists in introducing a new article the first cost of which is high compared with competing vehicles, and the details and possibilities of which are but little known. I should like to emphasize that the one thing needed to give the electric vehicle industry the success which it deserves in this country is money. Without a considerably more active and costly business campaign than is being provided at present, I think it will be a very long time before the electric vehicle will make any great headway or bring into the central stations that large revenue which I am confident is to be obtained from this business. I think that at the present time there could not be a better speculation for persons interested in the electric vehicle or in the supply of electrical energy than to undertake ordinary haulage work by means of electric vehicles in the same way that it is done to-day by means of petrol and steam lorries. In any of the large centres a considerable business is carried on by contractors who convey goods of any kind by contract ; and from information that I have collected there appears to be no doubt that where heavy goods have to be conveyed within limited distances this work could be done by electric vehicles at a much lower rate than is to-day charged for the use of steam and petrol tractors. I believe that the manufacturers of electric vehicles are alive to the possibilities of such business, and I can only conceive that the difficulty in securing funds is the sole reason which has so far prevented anything being done on these lines. I would commend the proposition to the attention of the more prosperous electricity supply companies. At the present time there is also considerable difficulty in getting delivery of vehicles, and the number available for demonstration purposes is very small. After carrying out a considerable amount of costly advertising and canvassing and securing a customer for an electric vehicle, it is very disappointing to find that he may have to wait several months for delivery, during which time he is continually exposed to the propositions of the makers of petrol vehicles who quote considerably lower prices ; and he also sees around him the ever-increasing number of mechanically-propelled vehicles of other types, and is, I am afraid, very apt to wonder whether he has made a mistake and embarked upon an expensive experiment. Immediately, however, that the electric vehicle gets into action the position is changed and the case immediately strengthened for further sales. In the comparatively short experience that I have had with these vehicles I have found no cases of dissatisfaction of any kind. I need not here dwell upon the advantages of the electric vehicle, but would say that they are very rapidly appreciated by the purchasers, particularly if the latter have been accustomed to the various forms of petrol-driven vehicles. With regard to the possible magnitude of the vehicle business, I have come to the conclusion that if in West Ham we had for regular charging a fleet of some 1,200 vehicles of mixed sizes—by no means a large number for that district—they would take practically as much electrical energy as is at the present time supplied to the Corporation tramcars, and that without increasing the maximum demand on the generating station in the winter-time. With regard to the cost of electrical energy for charging, it is certainly desirable that this should be kept down, and I think that

Mr. Beauchamp. such a price as $1\frac{1}{2}$d. per unit—which I understand is quoted in some districts—is distinctly too high; but at any price between $\frac{3}{4}$d. and 1d. per unit I anticipate no difficulty whatever in getting this business. The cost for energy apparently accounts for only about 20 to 30 per cent of the total cost of running electric vehicles, so that the precise figure is of less importance than it is sometimes stated to be, and at the same time it must be borne in mind that if any considerable number of vehicles were charged regularly on the premises of an electricity supply undertaking there would be incidental costs with regard to receiving and dispatching, protection from weather, attention, etc., which would reduce to some extent the actual price obtained for the electrical energy.

Mr. Mitchell. Mr. R. J. MITCHELL: I agree with the last speaker in his very appropriate reference to the industry, and particularly with regard to his views on the charge for energy. I have heard of a rate as high as $1\frac{1}{2}$d. per unit, but am convinced that such a tariff would be a very serious mistake indeed; in fact, the ideal should be to make it 0·75d. rather than 1d. I should like to call attention to the fact that there is an idea in some quarters that the electric vehicle is a direct competitor of the petrol car. That view of the question is not really justified. The electric vehicle is more likely to compete with the thousands of horse vehicles which are at present blocking the streets—particularly in large cities like London—and rendering the competition of all mechanically-propelled vehicles practically abortive, in fact curtailing their usefulness to such an extent that I understand only about 15 ton-miles are being obtained per gallon instead of the 35 ton-miles that ought to be obtained. I feel also that there is very great need for a large amount of research in connection with the vehicle problem in general: I refer particularly to the very small amount of knowledge that seems to be available as to the cost of operation. The figures that are quoted, for instance, in connection with petrol vehicles, vary so much, depending upon whether they are quoted by manufacturers trying to sell or by users who have bought, that one cannot help feeling that such figures must certainly not have been calculated in a scientific manner. It seems to me that it would be a very valuable contribution indeed to our knowledge of transport if the University of London were to follow the lead of the Massachusetts Institute of Technology and start a Department of Vehicle Research, in which they would survey impartially the whole field and give us really reliable information covering the three principal methods of city transport. After all, the electric vehicle will mainly be applied, at any rate in the first case, on city highways, and for that reason it would add very much indeed to the confidence of prospective users if they were to have the opinion of a scientific body of men who had independently investigated the question, rather than the assertions of manufacturers and agents trying to sell the vehicles before they have really got a considerable number of them on the road. Referring to the research aspect of the question again, I should like to state how valuable I consider it would be to go on with the research with which I think Mr. Shrapnell-Smith was associated in the very early days of petrol cars; I refer to the accurate measurements of road resistance. I believe Mr. Shrapnell-Smith, with Dr. Hele-Shaw, started such an investigation about 10 years ago. I also believe that this investigation did not eventually cover the field which it was originally hoped it would cover. Taking into account the very great improvements that have been effected in accelerometers during the past 10 years, and the fact that measurements of road resistance are now very simple indeed, it would seem that quite a small amount of work, in fact only a few thousand hours' work, would cover all the principal types of roads and districts in the United Kingdom. Another point is that the central-station engineer should not be expected at first to spend a great deal of money on providing facilities for charging, but that where it is possible to provide facilities by spending only quite a small sum he should provide those facilities, even though he had to wait several months for the arrival of the first car, because it would have such a very great moral stimulus for a man owning a car—for example, a pleasure car—to know that if he went to Guildford or Hindhead or some other place about 30 miles from London, he could be reasonably sure of obtaining a supply of energy to carry him back. Although the pleasure car is probably an offshoot, it is valuable to the industry on account of its advertising value; and it is perhaps also valuable in the hands of a few enthusiasts who like a car because it is an electric car, because it represents one step towards the ultimate all-electric touring car. That type of purchaser ought to be encouraged because his enthusiasm is a valuable asset. He talks about his electric car, he interests other people, and the result must in the long run be a definite advance in the movement. A small technical point to which reference should be made is the decision that earthing is not necessary in the case of the connections to charging plugs. It is possible for conditions to arise where the potential difference between the frame of the car and the earth can be as high as 230 volts or even more; and taking this into account and the fact that charging may sometimes be done in rather wet yards, I hope the Electric Vehicle Committee will reconsider their decision on that point and in fact alter it, for I am confident that a few years' experience, bearing in mind the type of man who will very frequently handle electric cars—unskilled labour being possible in consequence of their simplicity—will prove that accidents will otherwise occur.

Lieut. Sladen. Lieutenant S. SLADEN, R.N.: It is fairly well known that there has been an increasing number of electric vehicles in use by the London County Council Fire Brigade for the last four years. Members may be interested to hear some particulars of the vehicles that we have found so satisfactory. At the present time we are using lead batteries with 84 cells, with a capacity of about 200 ampere-hours at the 6-hour rate. The current is controlled by a series-parallel controller and led direct to motors in the wheels without the intervention of any gearing. The total weight of each vehicle is about $5\frac{1}{4}$ tons when fully equipped with men, that is, about 5 or 6 cwt. heavier than a similar petrol vehicle. The contract speed on a level road is 25 miles per hour, and that has generally been exceeded. The contract speed on a gradient of 1 in 19 is 15 miles per hour. The circuit-breaker is set at 250 amperes, so that a considerable current may be used in breasting a hill. The results that we have had with these vehicles have been so satisfactory that we have in a measure adopted them

as a standard for life-saving appliances in localities where the gradients are moderate. The fact that they have been adopted for that purpose will show that we have considerable confidence in their reliability. Of course there are limitations to the use of electric vehicles even for fire brigade purposes. There is a limit in mileage and there is the question of uniformity, because it is rather difficult, if not impossible, to have a complete electrically-equipped station, the difficulty being that a prime-mover other than electricity is required for a pumping engine, at any rate for a power-pumping engine which may have to run at full speed for perhaps 12 hours or so. Where electric fire engines have been adopted—there are none in this country, but in Germany, Holland, and other places—there is a battery in front and a steam fire engine and pump on the back, or in some cases a petrol engine and a radiator on the back. That presents rather an odd appearance. As to the cost of maintenance, I am afraid that I cannot give any figures which would be of much use to commercial users of electric vehicles, and I fancy that it will perhaps be a shock to those engineers who think that electric vehicles can be run very cheaply, when I say they have cost us about 1s. per mile to maintain, that figure not including drivers' wages or first cost or depreciation. But perhaps their feelings will be changed when I tell them that for similar petrol vehicles the cost is 1s. 3d. per mile. When one takes into account the first cost and the depreciation, the cost of maintenance of an electric fire-escape van and of a petrol fire-escape van are practically the same, namely, about £150 a year, allowing for interest and depreciation. The annual cost of repairs for an electrical escape van that runs about 800 miles per annum is £40, that is, allowing for renewals of batteries and so forth. We have had no particular troubles with the lead battery, although we are just beginning now to get the renewals that we expected to do, having regard to the experience of German fire brigades where the vans are run for about 3,000 miles before the positive plates require to be renewed, and about 6,000 miles before the whole battery requires renewing. It might be thought that trouble would arise through sulphating, but we seem to have got over that difficulty by arranging to discharge the batteries down to about 1·9 volts per cell every 2 months, and then to fill them up and give them intermittent overcharges. No trouble has arisen in that connection, although of course the cells lie idle for some time, and they are always topped up directly they get back to the station after a run. In fact I should have said there is a proper set of charging apparatus in every station. As to the difficulty of getting current of suitable voltage, we require for our batteries only about 30 amperes, and a maximum voltage of 240 for finishing the charge, the pressure at the start being about 180; but very few supply undertakings in London let us have current at a pressure less than about 400 volts. Either we have to waste a great deal of energy in charging, or else a generator has to be installed, which is a considerable expense, although on the other hand I quite recognize that from a charging-station engineer's point of view there is very little in it, because the bill at most of the stations comes to only about £2 per quarter, so that it cannot be expected that they will put themselves about for us. Among the advantages of electric vehicles for fire brigade work, we find that they require repairing less frequently, and that the rapidity of turn-out is absolutely unequalled by any other form of traction: it is not uncommon at an electric-motor fire station under ordinary service conditions for a turn-out to be effected in 7 or 8 seconds, whereas with other forms of motors a good turn-out is perhaps 15 seconds. That is a very great point with us, especially for the life-saving appliances. Another point is that the battery, being at the very top of its potential when there is a call, starts in the very best trim, and the maximum speed is at once attained, whereas with other forms of traction, namely steam and petrol, a little time has to elapse before things become quite normal. As most of our runs for life-saving purposes are for distances of only about half a mile, the advantages certainly lie with electricity. Another very important point is the provision of electric braking as an addition or auxiliary to the ordinary mechanical brakes. When we are exceeding the speed limit we find that a rather useful facility. In conclusion, I should like to say that after four years' experience I agree with Mr. Ayton as to the advantages of the electric over other power-driven vehicles in regard to its simplicity of construction, its low cost of maintenance, its ease of driving, and its general reliability; but I can offer no opinion as to the commercial efficiency of electric as compared with petrol and steam vehicles.

Lieutenant Sladen.

Mr. Mossay.

Mr. P. A. Mossay: As the agent of an electric vehicle manufacturer and one who has been personally concerned with the design of a particular class of vehicle, I propose to discuss some of the problems connected with the use of electric vehicles and of interest both to the consumer and the manufacturer. With regard to efficiency, the greatest claim of the electric vehicle, and one which is readily admitted by everybody, is its high efficiency, *i.e.* the relatively small amount of power required for propulsion per ton-mile at a given speed. This has been attributed to the simplicity of the electric chassis, which contains a minimum amount of moving parts, and to the high efficiency of the electric motor. This, however, is only one of the factors, as road resistance, tyres, etc., have sometimes a much larger influence than the resistance of the vehicle itself, especially if the vehicle is moving at a low speed so that wind resistance is of little importance. To take an example, let us consider tyres. I had an opportunity some years ago, whilst developing a particular type of vehicle, to test various makes of tyres; and I here propose to refer to three typical ones. The vehicle was a small delivery van weighing 1 ton 8 cwt. In the first test solid tyres, 800 × 65 mm., were used; in the second test the tyres were 760 × 90 mm.; and in the third test 765 × 105 mm. The power consumption at a speed of 14·4 miles per hour was 186, 212, and 260 watts respectively. The tests were made on good paved roads. The conclusions to be drawn from these tests are obvious; in the first case the theoretical mileage which the car would run with a 132 ampere-hour battery would be 54 miles; in the second case 47 miles; and in the third case $38\frac{1}{2}$ miles. The facility with which it is possible to state in concrete figures the performance of an electric vehicle is an element of its reliability, and affords a means of keeping the vehicle in a constant state of high efficiency. The performance of the battery is influenced by the current that is taken by the vehicle, and in connection

with lead cells—with which I have had more experience than with alkaline cells—I may say that the maintenance will thus be influenced by the performance of the vehicle. It is a case therefore where the battery manufacturer should work hand in hand with the vehicle manufacturer and adjust maintenance rates to the performance of the vehicle. If we take the two extreme cases just given, where the same vehicle shows a theoretical mileage of either 54 or 38½ miles, it seems to me that a flat maintenance rate per car-mile would penalize the higher efficiency. Electric vehicles are very economical in tyres. In one of the large taxicab undertakings in Germany, which operates 115 Lloyd electric cabs and over 30 petrol cabs of various makes, the records of 5 years' experience show that tyres last 80 per cent longer on electric cabs than on petrol cabs. This, on bad or indifferent roads, points to even better results in this country. To sum up, I wish to say that wherever conditions are suitable and electric vehicles have been given a fair chance, they have come to stay. The Hamburg Taxicab Company started in 1907 with 25 electric vehicles, and has steadily increased the number to 115. The General Post Office in Berlin, which bought 2 Lloyd cars in 1906, has now over 100 electric vehicles and is contemplating further additions. The General Post Office in Copenhagen is now operating 13 vehicles; Leipzig 26, the Taxicab Company in Amsterdam 44, and the Municipality of Altona 23 vehicles. [Mr. Mossay showed a series of slides illustrating the types of vehicles referred to in his remarks.]

Dr. C. PORTER: I feel sure that it will be to the advantage of public health to have electric vehicles on our streets. I remember on one occasion hearing the late President of the Local Government Board, Mr. John Burns, state in an address on infantile mortality that there was no doubt that the lives of many children had been saved by the transformation of stables and mews into garages. I absolutely agree with that statement; but I think that against the advantages of getting rid of the horse have to be placed two disadvantages of the petrol-driven motor, namely, the contamination of the air which it produces and the noise which it causes. I feel very strongly that noise, more particularly noise in the night, seriously interferes with health. Even if one is not awakened, I am quite sure that one's nervous system, the brain especially, is injured by being over-stimulated, with the result that it is not properly rested. The noise produced by motor cars is particularly irritating and shattering to the nervous system. I remember some years ago, when I was engaged in school medical work, picking out in a school several little girls—whose parents were in quite good positions—who looked very tired and fagged, and who, I was informed, were not taking advantage of the education provided for them. On making inquiries I found that these children resided in a street along which tramcars passed; they did not sleep well, their sleep being disturbed by the noise of the cars, and each morning they came to school dull and unrested and unable to concentrate their attention on their work. The case of these girls, and others that I have since met, impressed me very greatly and helped to strengthen the opinion that night noises are objectionable and distinctly detrimental to health. The other objection to the motor, namely, the contamination of the air, is one which it shares with the horse. The contamination is not exactly of the same type, but there is certainly contamination of the air just as objectionable from vehicles driven by means other than electrical as from the horse. Anybody who on a warm summer's day walks from the Marble Arch towards the City will have no difficulty in finding evidences of contamination of the air from motor-driven vehicles. He will find that his nose, throat, and eyes are assaulted by something given off by the motor cars, and all these irritations of the mucous membrane give rise to considerable discomfort in the shape of headache, smarting eyes, and sore throat. Anything which gives rise to discomfort interferes with health, and all of these are discomforts, if nothing worse. People who have to work hard—and we all have to work hard nowadays, and to work at a great pace—must have comfort; and interference with comfort in any way, even by petrol-driven cars, is to be avoided. If they can get rid of the contamination of the air, and if it is possible to get rid of some of the traffic noises by introducing electrically-driven vehicles, electrical engineers will do a great deal for the public health, and I, at any rate, will support them as a public health man.

Mr. C. BARBER: I have been rather impressed by the hesitancy of borough electrical engineers to look upon electric battery-driven vehicles seriously, and they do not seem to realize that the present-day electric vehicle is a really practical mechanical job. The present-day battery is quite different from those of past years, and there are many makes which are quite satisfactory. The great point to be borne in mind is the relative working cost of electric battery vehicles compared with that of petrol or steam-driven vehicles for similar work. Naturally, in this country very little experience of working costs has been obtained up to the present time, but a great deal has been learnt from Continental and American experience. As far as it is possible to estimate the conditions in this country, I think it will be found that battery-driven vehicles for short-distance work, say 20, 30, or 40 miles per day, compare very favourably indeed with, and work at 20 per cent less cost than, petrol-driven vehicles for the same class of work. I do not doubt that the cost of repairs would be much less in the case of electric vehicles than for steam and petrol-driven vehicles. The adoption of battery-driven vehicles in this country will, I think, be found to rest almost entirely upon the question of working costs. Of course the facility for charging and similar questions are also wrapped up with it. To start with, there is a large field for the use of battery vehicles for corporation and municipal purposes, and if borough electrical engineers could only be induced to put forward the benefits that would be derived by their own department and by the borough from the use of electric vehicles, I think a great step forward would have been taken.

Mr. A. B. PESCATORE: Mr. Ayton at the end of his opening remarks said that we have got to educate the public. I think we have something more to do than that. We have to satisfy the public that the electric vehicle can be run, at any rate for commercial purposes, more cheaply than a petrol vehicle. Mr. Mossay has omitted an important point about the electric chassis, namely, that its life can be assumed at about double that of a petrol chassis doing the same work. Taking the petrol chassis

as having a useful life under hard working conditions of about 5 years, the electric vehicle certainly has a useful life of 10 years. That being so, to satisfy the public that the total costs will remain within certain limits, which I believe will be 20 or 25 per cent below the cost of similar petrol vehicles, battery makers at any rate will have to guarantee to the users that their costs per mile run for those 10 years will not exceed a certain sum, and they will have to see that such a figure can be obtained. At present the cost of maintenance, taking only the renewal of materials and not the labour for repairs or the handling and charging of the batteries, will vary between 1d. per mile for a 3- or 4-wheel vehicle weighing 5 cwt. to perhaps $2\frac{1}{2}$d. for a 5-ton van, these weights being the useful load in both cases. If instead of merely supplying materials one provides the labour for repairs, superintends the charging of the cells, and in fact attends to everything in connection with the battery except its removal to and from the car, the cost will be for the same two vehicles about $1\frac{1}{2}$d. and $3\frac{1}{2}$d. respectively. Those figures have been obtained on a number of vehicles, perhaps 60 in this country and probably 10 times that number on the Continent, some of which have been working for something like 7 or 8 years. In this country, for instance, a fleet of 15 omnibuses has been working at Brighton for 6 years. Each omnibus weighs nearly the same as a 5-ton van, and they are working under unfavourable conditions, the roads being bad and the gradients in some parts very severe. There the cost has remained below 3d., including all the supervision during charging and the handling of the batteries, but not their removal to and from the vehicles or the supply of current. As regards the energy consumption, the figures that have been obtained vary between 110 and 140 watt-hours per ton-mile. For a vehicle of 2 to $2\frac{1}{2}$ tons useful load and a total weight of 5 tons, the figure will be about 600 watt-hours. For a larger vehicle it will be less in proportion to the weight; for a smaller vehicle a little more. The consumption of energy for charging will then be one-third more, and the efficiency of the battery in practice will be the same, namely, 75 per cent, a figure which applies to all makes of lead batteries. In addition to those omnibuses there are a number of other vehicles, such as fire-engines, where the cost per mile would have no meaning, as the mileage is so very small; but for vans for the carriage of goods and for any vehicles like omnibuses which would run 30 miles or more each day, those are the present figures. They are obtained with batteries which are exactly similar to the batteries that were first used in the same omnibuses before these were transferred to Brighton. Some of them at any rate were used for about two years by the now defunct Electrobus Company in London, and it was not owing either to the batteries or to mechanical or electrical causes that this Company came to grief; it was entirely financial troubles that killed it.

Mr. Fox. Mr. M. E. Fox: One of the popular ideas concerning the battery vehicle is its apparently limited radius of action. When we are told by the manufacturer that his vehicle is capable of running 50 miles per charge, we are too apt without a thoughtful analysis of the conditions of normal delivery service, to assume that its free use is thus handicapped. Actually it is seldom that a greater distance than 50 miles is covered during the hours of the usual working day, owing to the fact that time is lost in loading, unloading, and making house-to-house deliveries. For instance, one London firm which has been using a commercial van of this type during the past year finds that it runs on an average 32 miles per day. In those cases where the delivery limits approximate too closely to the total mileage of which a vehicle is capable, it must be borne in mind that an hour's charge at a high rate, while the driver is taking his midday meal, increases the possible mileage by 30 per cent. Furthermore, there would be no great difficulty in designing a commercial chassis capable of propelling itself 100 miles per battery charge, as there is usually considerable spare space on the ordinary chassis that might be utilized in adding a larger battery; but such a vehicle would find only a small market, in comparison with the present type. The latter has of course been designed with the proportions best suited to ordinary running conditions. One of the items contributing to the low cost of maintenance of this type of haulage is that the driver's attention is quickly called to the fact that adjustments are necessary, and he can attend to them before they become serious. Thus, any increase in the current is at once apparent, so that a hot bearing, a rubbing brake-shoe, etc., may at once be investigated. In the case of the petrol vehicle faults are not so easily detected, no direct-reading instrument being provided to show the consumption of power, and the engine taking up its increased load uses an increased amount of fuel until the breakdown occurs. It therefore requires the constant attention of a careful mechanic to keep the petrol vehicle at its highest efficiency, while, due to the simplicity of the warning given, the neglect of the driver of an electric vehicle to note the condition of his car would be unpardonable. The gain, then, is twofold, for being easily kept at its highest pitch of efficiency, less energy is required for the operation of the electric vehicle, and serious breakdowns, with their resultant interference with normal delivery service, are avoided. By using any of the various types of recording devices now on the market, accurate running costs can easily be ascertained, with the result that the owner is encouraged to analyse the methods of delivery and observe where economies might be effected. How different, however, is the condition of affairs in the case of the usual horse-owner. He is in most cases blissfully ignorant of just what it costs him per ton-mile to move his goods, and when questioned on this point will usually name a figure considerably below the actual cost, merely because he has not the facilities for obtaining accurate data concerning his horse-haulage. He feeds the horse; it carries his goods; and there the matter ends. In attempting to electrify the public's system of transportation, therefore, the advocate of electric vehicles does not find his path easy. It is at this point that the central-station engineer has an opportunity of aiding the cause by assuring his power consumers that the electric vehicle is an admirable vehicle and that he has at a tempting price and in unlimited quantities the energy required to propel such a vehicle. Electric traction in its most economical form can best be realized when the size of the vehicle is correctly proportioned to the work usually required of it. To use a 2-ton van for carrying a 3-ton load habitually would tend to increase the cost of

Mr. Fox. maintenance considerably, because the best vehicle manufacturers design the motors, frames, and tyres for the rated load, and so look with concern on the user's attempt to gain economy in this manner. It is for this reason, broadly speaking, that the use of trailers with electric vehicles is not encouraged. In the popularizing of the electric vehicle, the manufacturer of electrical apparatus, other than storage batteries, should not lose sight of the fact that he is interested in the outcome. Usually each purchaser of a van is a prospective buyer of at least a motor-generator, switchboard, and accessories. Manufacturers, therefore, should be among the first to regard favourably the adoption of electric transportation. It is strange to find that most electrical engineers are poorly informed upon the possibilities of the battery vehicle. In justification of this it might be advanced that electric propulsion has never been utilized on a large scale in this country. Although it has been used for slightly over a decade in America, the subject has taken such a firm hold of the public that it is now seriously proposed to make a course in electric vehicle practice a part of the curriculum of the principal technical schools, to ensure that the coming engineer starts his career with at least no erroneous ideas concerning this form of transportation. This subject can certainly be brought to the attention of the layman most appropriately through the electrical profession, and as the furtherance of this movement can bring only benefits to the profession, we can at least give it our encouragement and protection.

Mr. Brazil. Mr. H. BRAZIL: Through the courtesy of Mr. Turton of the Tudor Accumulator Company, I had the pleasure yesterday afternoon of driving what I am informed is the largest commercial electrical vehicle either in this country or on the Continent, and it may be of interest if I give some particulars of its capacity and equipment. The weight empty with a 250-ampere-hour battery is 4½ tons, and it will carry a load of 5 tons, making a total weight of 9½ tons. The maximum speed on the level when loaded is 9½ miles per hour. The consumption is about 1 unit per mile loaded; that is, allowing for the 75 per cent which Mr. Pescatore gave as the efficiency of the battery, about 1·3 units are used per mile in this lorry with its full load of 5 tons. The standard battery consists of 80 cells, divided into 2 units of 40 cells each, with a capacity of 250 ampere-hours, and with that battery a range of 35 miles on the level is obtainable with full load. A larger battery, such as that on the vehicle which I drove, has a capacity of 300 ampere-hours and gives a range of 45 miles with one charge. The driving is very easy; I had never driven an electric vehicle myself before, but found no difficulty in driving this one. The only point to notice is that being 20 ft. long it is necessary to be very careful when going round corners, especially with such a heavy weight as 9½ tons. One other point in connection with the lorry is rather interesting, namely, the method of control. This may be familiar to many members, but was new to me, and I think it brings out a very important point in connection with electric vehicles, that is to say, the reduction of the maximum current taken from the battery, thus making the battery load factor as high as possible. That is done in this vehicle by not only putting the two motors in series, but also arranging the two halves of the battery in parallel. On the first notch the batteries are connected in parallel and the motors in series, with a resistance in circuit. On the second notch the motors are still connected in series and the batteries are still in parallel, but the resistance is cut out. On the third notch the batteries are in series, the motors still being left in series and the resistance cut out. On the fourth notch the motors are connected in parallel, but the field coils are left in series, so that a lower speed is obtained owing to the whole of the current having to go through each field coil although it is divided between the two armatures. Finally, at the highest speed, 9½ miles per hour, the two batteries are in series, the two motors in parallel, and the field coils also in parallel. Passing beyond the zero point one gets on to the electric brake, which is the ordinary arrangement where the whole resistance is first in series with the motors, then half of it, and thirdly the whole of the resistance is cut out. That gives a very good braking effect; in fact, in the case of a novice it is rather dangerous, because if the lever is pulled right over, one is apt to be thrown off the front of the car, since the latter pulls up within half its own length. The point that I particularly wish to impress on the meeting is the advantage of keeping the load factor on the battery as high as possible. This is important, not only because of the buckling of the plates caused by heavy discharges, but also because it very largely affects the total number of miles that one can go with a single charge. I think that it is not generally appreciated to what extent the capacity of a storage battery, of the lead type at any rate, is affected by the discharge rate. To enable me to illustrate my remarks I would emphasize two figures. We can obtain from a lead storage battery, when it is discharged at the 10-hour rate, twice the capacity that is available when the whole discharge takes place in one hour. That is a very considerable difference and one which, if the discharge rates are heavy, will materially reduce the distance that the vehicle can travel. This brings up the very real difficulty in connection with electric vehicles of determining at any moment to what extent the battery has been discharged. How are we to know how much of the charge is left? It may be said that if we know how much has been discharged then we know how much is left; but that is quite wrong, owing to the fact that the capacity varies so enormously with the discharge rate. We do not therefore want to know so much what is taken out of the battery, as how much is left in and available for work. The difficulty in the past has been to get an instrument that will give us this information with reasonable accuracy, the ordinary ampere-hour meter being useless as it does not take into consideration the variation of capacity with discharge rate. I thought therefore it would be of interest if I were to describe a meter which Mr. F. Lydall and I devised some time ago, and which I think solves this particular difficulty. A meter is required which not only takes into consideration the number of ampere-hours which are passing through it, but also the rate at which those ampere-hours are being discharged. I venture to suggest that the meter I am about to describe fulfils this requirement. As will be seen from Fig. 1, there are two discs, the top one of aluminium and the bottom one of celluloid, mounted on one common spindle, each having a winding, these windings being connected in series and taken to one commutator. The top

Mr. Brazil.

disc is embraced by the ordinary permanent magnets, and the disc being of aluminium, this provides the braking power necessary. The bottom celluloid disc is embraced by two electromagnets, excited by the main current coming from the battery or by a current proportional thereto. In an ordinary instrument of this type the speed of the disc is proportional to the current in the main circuit, but as there is no braking on the bottom disc it will be seen that the speed of rotation of this meter is not proportional to the current as in the ordinary instrument, but to the current multiplied by a factor, this factor increasing as the current increases. The meter is provided with one large dial divided up into 100 divisions, and the pointer works backwards through 90, 80, etc., to zero; when the zero point is reached it indicates that the battery is empty. The windings and mechanism are so proportioned that when the battery is completely discharged the pointer will move

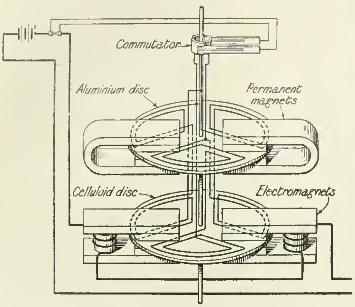

FIG. 1.

from 100 to 0 whatever the discharge rate, and in spite of the fact that the number of ampere-hours may be twice as great in one case as in another. The meter, of course, does not register ampere-hours, but only gives an indication at any moment of the proportion of the total capacity of the battery that is still available for use.

Tests were taken with this meter in circuit with a small Tudor accumulator, and the results are embodied in the curves shown in Figs. 2 and 3. The voltage at which the discharge must cease in order to prevent injury to the battery varies with the discharge rate, being 1·7 volts for the one-hour rate, and 1·83 volts for the 10-hour rate. The values of the ordinates in the two curves are obtained by subtracting this minimum in each case from the actual voltage observed, so that when the curve crosses the zero line the battery is discharged. In Fig. 2 the abscissæ are ampere-hours, and it will be seen that with a discharge current of 9 amperes, *i.e.* just below the one-hour rate, the battery is empty after giving out 10·5 ampere-hours, whereas when the discharge takes over 10 hours (1·75 amperes) the number of ampere-hours is 21. In Fig. 3 the abscissæ are the divisions on the dial of the instrument and it will be at once noticed that whatever the rate of discharge, the pointer comes very nearly to zero when the battery is empty, that is to say, when the curve crosses the zero line. The question might be raised as to whether the meter would indicate correctly with a varying rate of

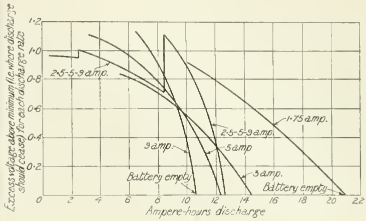

FIG. 2.

discharge, and in order to demonstrate this I took a curve which is shown in Fig. 3. In this case the first part of the discharge was at 2·5 amperes, the second part at 5 amperes, and the third part at 9 amperes, and yet the curve crosses

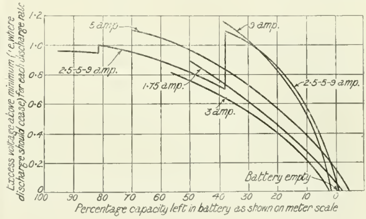

FIG. 3.

the axis at practically the same point as the other curves. It must be clearly understood that, for this meter to register correctly, at the commencement of the discharge the battery must be fully charged and the pointer at 100. An automatic device for setting the pointer at 100 when the battery is fully charged has been introduced in the design.

Mr. Makower.

Mr. A. J. MAKOWER: With reference to Mr. Mitchell's suggestion that the London University might assist in carrying out some tests on electric vehicles, I am Secretary of the Board of Studies of Electrical Engineering and I am sure that there are a number of people on the electrical side of the University who would be only too pleased to carry out any tests that are required. The electric vehicle enables problems to be investigated which cannot be undertaken by any other means, because of the possibility of avoiding the very complicated measurements that are necessary in other cases. The following figures will be of interest in that connection :—

Mr. Makower.

TABLE I.

	Total Weight, Tons	Useful Weight, Tons	Speed, Miles per Hour	Watts	Watt-hours per Car mile	Watt-hours per Ton-mile
5-cwt. lorry ...	1·43	0·25	15	2,850	190	133
Taxi-cab ...	2·1	0·25	16·5	4,245	257	122
1½-ton lorry...	3·6	1·5	12	3,460	288	80
2½-ton lorry...	4·9	2·3	12	4,250	354	72·4
Fire-engine ...	6·0	—	15	4,830	322	53·6

The figures are not for any particular car, but are averaged over a number of vehicles, some of the vehicles being cabs and some fire-engines. They show how the number of watt-hours per car-mile and per ton-mile depend on the weight carried.

TABLE II.

Battery upkeep	0·99d.	per car-mile
Current	0·90d.	,,
Tyres	1·874d.	,,
Driver	1·564d.	,,
Repairs to chassis	0·71d.	,,
General expenses	0·632d.	,,
Depreciation at 10 per cent	0·33d.	,,
	7·00d.	,,

Table II shows some figures relating to an electric cab company that has been running its vehicles for about six years in Germany. At present 100 cabs are running, and evidence of their reliability is the fact that the cabs average 350 days' work in the year, the average figure for cabs out of service not exceeding 4 per cent. The battery figure is considerably lower than the one that Mr. Pescatore mentioned. The batteries are not run under the manufacturer's guarantee, and they can be run more cheaply by users who employ a staff of sufficient experience to carry out their own battery repairs. The cost of the energy is about 1·1d. per unit. The figure for the tyres, 1·87d., is higher than it would be at the present time, because the figures relate to two years ago when the price of tyres was higher than it now is. The figures for drivers' wages may appear to be very high, but it must be borne in mind that these cabs are running a day and night service, and the figure of 1·56d. per mile includes the wages of two drivers. The total cost—about 7d. per mile—is a good result. I think that the figure for the energy consumed points a moral for the central-station engineer: 0·99d. per mile may not look very much, but on the present basis of 31,000 miles per cab per year it means that about 2½ million units are sold to this company per annum, representing £11,500. On the basis of a 24-hour charge—these batteries are being charged day and night, and there are more batteries than vehicles—that is equivalent to a steady load of 300 kw. When this cab company started with a few cabs, the electrical engineer of the town might not have considered it a very important undertaking, but when he has to supply energy to the amount of £11,500 per annum to one consumer, and for the best kind of load that it is possible to get, he would probably be willing to reduce the price, but by that time the consumer will have found it to be advantageous to erect his own generating station. This goes to show that central-station engineers should be more accommodating in the initial stages of the introduction of electric vehicles than they are in many cases at present. Some are taking this matter up very heartily, but I have met others who treat those who are proposing to use electricity for charging electric vehicles as though they were only installing a few lamps.

Mr. Burgess.

Mr. W. A. A. BURGESS: In the first place I should like to suggest that batteries for vehicles should be assembled in a removable truck on rollers running on suitable rails on the underframe, so that the complete truck can at once be withdrawn on to a charging wharf and if required a new fully charged one substituted. If these trucks are standardized for various duties, and maximum and minimum weights of trucks complete with batteries per h.p.-hour are published, the vehicle makers will then be in a position to provide standard chassis to take batteries by any maker. With the use of removable trucks there would be no need to rank the vehicles up for charging, and the batteries could be grouped much more effectively for charging and overhauling and could thus receive the full attention required to keep them up to maximum efficiency. The vehicles with batteries removed would be manœuvred in the yard by plug connections through flexibles for cleaning and general overhauling. It would still be possible when necessary to boost the batteries during fairly long halts. Given closer co-operation between battery manufacturers and supply authorities, it might be found advantageous in London and other towns to hire out, against a deposit, batteries fully charged, the charging and maintenance being always in the hands of the joint authority. By the provision of a slightly larger number of spare batteries the charging could be controlled by the supply authorities to suit the load factor of the system, and for this reason I suggest that a vehicle voltage should be chosen approximately half that of the average continuous-current supply voltage, where it is possible to average this, and twin cells used so that they could be charged in series and discharged in parallel, with a considerable saving in resistance losses. A system such as this could easily be arranged so that the batch of batteries in reserve could form some sort of stand-by to the local lighting network in the case of the smaller undertakings and localized distribution systems. With regard to the control of battery vehicles, a considerable saving of energy could probably be effected by the use of tappings off the battery in the place of resistances, a suitable change-over switch or switches being provided to enable the starting current to be taken from any required group of cells and interlocked with the controller so that the act of cutting off current ensures that a different group of cells shall be used to provide the starting current next time, thus discharging the whole of the battery equally. The suspension of the motor is an important matter to which attention should be given, because on it depends the total unsprung weight that is taken on the axles, which very largely affects the upkeep of tyres. I should like to see figures published by the

Ir. urgess

battery makers for the approximate maximum and minimum cost of batteries per h.p.-hour, as this seems a more workable figure for those whose knowledge of electric vehicles is necessarily entirely non-technical.

Ir urnand.

Mr. W. E. BURNAND: In the first place I regret that I cannot disagree with those speakers who said that the electric vehicle is not a competitor of the petrol vehicle. I would say, however, that the petrol vehicle cannot compare, and is not a competitor for certain services, with the electric vehicle, also that with improved design and greater knowledge the first statement will not long hold good. In my own case I require deliveries at infrequent and very irregular intervals, and I have both petrol and electric cars available, but it is the electric car that is always taken out to do the work. The determining factor is not the third decimal place in the cost of running the cars, but that the electric vehicle can be driven by anybody, whilst the petrol car cannot. Any man that happens to be available in the shop can go out with the electric vehicle, and he gets the work done in about the same time that it takes to find a man who can drive the petrol car. Apart from the variation of the capacity with the rate of discharge, the mileage obtained by different drivers varies greatly, especially where there is much traffic, as one man will keep using the brake to slow down, and taking it off again to speed up, without moving the controller handle, whilst another man practically never uses the brake but varies the speed merely by working the controller properly and coasting as much as possible. The variation possible in this respect is as much as 50 per cent. For short runs, however, this is not very serious, as the increased cost of the energy used in a run is seldom more than 1d., whilst the time saved and the driver's time is probably worth about 2s. For hilly districts it seems to me important that the change of speed on different gradients should be greater than that obtained with a simple series motor; also that this variation should be out of the control of the driver, as an excessively high rate of discharge greatly shortens the life of the battery in addition to decreasing its efficiency. It seems to me that the question of mileage is merely a matter of decreasing the friction and resistance losses, since it is obvious that in a round trip no energy is actually used apart from these items, and it is the possibility of keeping these losses exceedingly low that renders the electric vehicle a serious potential competitor of the petrol vehicle. Mileage seems to me to be merely a question of design, and it is by no means impossible to double or more than double the present range. Rapid deterioration of the batteries is mainly a question of the better education of the users. There is one other point that I want to mention, namely, regeneration. It has been tried with usually very indifferent results, but I am quite certain it can be made practical, and of great use for hilly districts —for level districts it does not promise much gain. I made an experiment last night on a short run, two miles out and two miles back. The first mile was on a very slight incline, and the second mile on a fairly steep incline. Going out we used 1·09 units, and on the return journey 0·122 unit, that is, not much more than 1/10th of the amount used on the outward journey. The weight of the vehicle and the load would be about 38 cwt. On making the same journey later on, first charging the battery up to the same condition as before, we used the same amount of energy on the outward journey, but returning down the hill we regenerated about 0·336 unit, or over the whole journey something like 30 per cent. That is quite worth having, not only on account of the 30 per cent saving, but because it keeps the battery in a better condition. There is, as a previous speaker said, a large reduction in the capacity of a battery on a heavy discharge. I have not seen a definite explanation of that fact, but it seems to me that what happens is that the surface layers get exhausted, and as the electrolyte cannot circulate readily in the pores of the plate there is a certain amount of local action between the charged part and the discharged surface. The result of regeneration is to charge the surface up again, and to save a very considerable loss in addition to the amount regenerated. One unit regenerated is worth about $1\frac{1}{2}$ units at the garage. If the approximately level part of the road were neglected and a test were taken on the steep hill mentioned above, the amount of energy regenerated would represent no less than 45 per cent.

Mr. Burnand.

Mr. Shrapnell-Smith.

Mr. E. S. SHRAPNELL-SMITH: I was associated for many years with the progress of the steam road vehicle, and then with the petrol vehicle, and it seems to me that the electric vehicle will very probably in the next few years go through some of the early stages of—I will not say trouble, but perhaps I might say lack of commercial appreciation through which the steam and the petrol vehicles successively passed in this country. I entirely endorse the remark that the electric vehicle will mark out its own place, perhaps not for its exclusive use but where it will predominate. It seems to me that those who are seeking to popularize the electric vehicle will have their best field of action primarily in cities. I was much impressed by the reference to the noise of taxi-cabs. One point, which I think is not fully appreciated, about the petrol vehicle is that the silence which has been developed with the help of the police and the designers of the motor omnibus in London is chiefly silence on the top gear. I have suffered, in common with everybody who lives in London who has a certain amount of mental work to do, from the difficulty of sleeping, not only while the taxicab driver's fare looks for his money, but much more so while the man is jerking his change-speed from the bottom gear upwards and reversing, generally with his tyres cutting a hole in the road. One of the great claims of the electric vehicle, to speak of the matter seriously, is that the electric vehicle is silent in all "gears," at all times, and at all speeds, whereas the petrol vehicle, however quiet it may be on the top gear, is not so quiet when it comes to work on some of the lower gears. With regard to the question of current, I think the point to be remembered is not a question of detail, such as the differences in consumption between different kinds of tyres on the same road, mentioned by Mr. Mossay, but that if one goes into the country and runs on various surfaces, including water-bound and sometimes water-logged macadam, the increase in consumption is often not 10 or 15 per cent but nearer 100 per cent. When one comes to country services that is one of the factors that will upset to a great extent the estimated mileage as determined by the amount of energy in the battery, and that will bring one back again to the superior claims of such a vehicle for short mileages in town work as a starting-off point—where in my opinion it will be welcome. I was much impressed

by the reference to the fact that money is wanted. I have often heard that expression used, and have used it myself: "The paralysing want of money" was a remark that fell recently from the lips of Sir George Gibb in connection with roads. There is not the slightest doubt that the steam and petrol vehicle industries established themselves in this country only by an accumulated charge during the first two or three years on what is termed the "suspense account," which sometimes has to be written off altogether. I think probably the problem is simpler for the electric vehicle industry; but I think it is rather too optimistic for the supply companies or the manufacturers to think that they will make money from the start. They will have to be prepared like the petrol industry and the steam industry had to be to fight against very considerable odds, whatever encouragement they may get for the first few years. There is only one other point. Costs are probably the most elusive factor in the whole of this problem; yet in the sale of commercial vehicles nobody can deny that the working cost is the factor to which every other consideration is subsidiary. It is only by producing convincing figures as to working cost and showing to the satisfaction of the man who wants to buy a vehicle, and who is not influenced by the quietness or the beauty of the suspension so much as by the reduction of 1d. per mile in the running costs, that it will save him money—it is only by bringing that fact home that the electric vehicle industry of this country will secure a large share of the road transport business. The difficulty that I am in is this. I have never yet, however much I have tried, through correspondence with various American people and in the pages of the many American journals which I see every week, been convinced as to what the cost of electric vehicle operation really is. I am sure that there must be many people in this country who are preserving a perfectly open mind, and they are merely waiting to be convinced by Mr. Ayton and others interested in this matter.

Mr. P. P. WHEELWRIGHT (*communicated*): In the early part of last year the Blackburn Electricity Committee decided that a motor car was necessary to keep up the efficient working of the department. Prices for petrol cars were at once obtained, and a guaranteed number of miles per gallon of spirit for each vehicle was asked for. On looking into these I was very much surprised to find that very few makers would give any figures, in fact it seemed to be considered an altogether unnecessary query. Personally, I think that the question of the cost per mile ought to be the main one when purchasing a car, especially in these days of high-priced fuel. Therefore, as an alternative, the purchase of an electric vehicle was considered. I obtained particulars and went into the matter fully, and found that although the capital cost would be high, the cost per mile, which was obtainable from most makers or agents, would be very much lower than any figure given by a user of a petrol car. After the question of low running costs, the following were the points that helped my Committee to decide upon the purchase of a battery car:—(*a*) Driving is practically a matter of steering alone, consequently no specially trained attendant is required, and no work in starting the engine, etc., is necessary; therefore no time is lost in getting the car away. When driven in congested traffic, where rapid acceleration is of great value, the car can be controlled with ease and precision. (*b*) The simplicity and reliability of the motors and the control arrangements, and consequently the low maintenance and repair costs. (*c*) The running of the car is perfectly smooth and silent, resulting in a longer life of the tyres. (*d*) The cost of housing the car is low, as no special provision for the storage of petrol and inflammable materials is necessary. (*e*) No emission of smoke or smell or vibration when the car is running or standing. (*f*) For an Electricity Department the car is the best advertisement possible, as its use keeps in view of the public the variety of purposes to which electricity can be applied. The insurance premium covering all risks that was paid last year by the Blackburn Corporation on their electric car was very high; and at the time I was not able to obtain any reduction, but I am glad to hear that as a result of the good work of the Electric Vehicle Committee there is every probability that the insurance premiums on this class of vehicle are to be reduced in future. This is very necessary, as the premiums, which are based on the schedules for an ordinary petrol car, are unfair when applied to a battery car, as the risks cannot be compared. The argument which I find is most frequently brought against this class of car is the comparatively short distance that it can be taken without recharging. This is most certainly a serious disadvantage, but I think there is every reason to hope that in the near future this difficulty will be overcome, and one must acknowledge the undoubted truth that at the present time there is a very large field for this class of vehicle for town use and local work, *i.e.* within 40 to 50 miles' radius. As far as the large capital outlay is concerned, in the purchase of these electric cars I think that an electricity department can very rightly allocate a proportion of the cost to the general advertisement and publicity account that all progressive undertakings find a necessity. The value of this class of car for breakdowns is without question, as it can be on the road and away in a few seconds after notification has been received, and should the trouble be in an underground manhole or substation, where light is required, portable lamps with long lengths of flexible can be plugged on to the battery, and neither wind, rain, nor carelessness can delay the work of repair. On looking up the figures as to the consumption of energy during the last nine months, I find that the average is 3 miles per unit, which in such a hilly town as Blackburn I consider a most satisfactory figure, and one that in many towns could easily be improved upon. To advance the adoption of electric cars by the public should be the aim of every electricity department and electricity supply company. To do this they must set an example themselves by employing these vehicles for the variety of uses to which they can be applied. The experience thus gained will be of value when considering the question of charging for this class of demand, and when specifying what will be necessary in the charging stations, which undoubtedly will be required in various parts of our towns. Another point is that the manufacturers should aid the electricity department and supply company as much as possible by giving demonstrations of the practical applications of the electric battery vehicle. In conclusion, my own experience of the use of an electric car has been highly satisfactory in every way, and financially there is no doubt that no other form of propulsion can at present compare with it. I trust that steps

Mr. Wheelwright. will be taken to enlighten and educate the public to the fact that the electrically-propelled vehicle is a sound financial investment which has come to stay.

Mr. Ruddock. Mr. E. N. RUDDOCK (*communicated*): In discussing the pros and cons of electric battery vehicles the question seems to resolve itself into two distinct parts, namely, the chassis, and the battery. With regard to the first, in these days of high efficiency motors and gearing, and ball and roller bearings, the very long life of all the component parts of the chassis due to the absence of vibration and reciprocating effects, also the extreme ease of manipulation and simplicity of control, make the electric chassis for many purposes much more satisfactory than either the steam or petrol chassis, and a life of 15 years is not too much to expect, as I know from personal experience. The real crux of the matter is the battery, which may be subdivided into (1) battery plates, and (2) current. The first is a matter for the accumulator manufacturers; and looking back over the past 15 years or more, very little real improvement in plates can be recorded. As regards weight and capacity we stand very much where we were then. Improved methods of manufacture and purity of material have probably increased the life of the plates to some extent, but compared with other branches of electrical engineering the lead battery for road vehicles has been practically marking time. The very nature of the material means a weak job mechanically, and therefore a limited life. The Edison battery is a distinct and notable breaking away from old traditions, and if the price can be reduced very considerably and the watt-hour efficiently raised, it will go a very long way towards solving this very difficult and important problem. The second point, viz. the question of current, is one for central-station engineers, who really seem at last to be awakening to the possibilities of the subject. Owing to the fact that the current will usually be required at a time when the ordinary lighting load is very light, this hitherto-despised load will very materially help to fill up the valley in the load curve between midnight and 6 a.m., and it would surely be possible to supply it at 1d., or even less, per unit. At this price the electric vehicle has a very great advantage over the petrol car; the price of petrol is still increasing and is likely to remain at a high figure until some other agent giving the same results can be produced. There is another point that the central-station engineer will be called upon to consider, and that is the question of having charging pillars erected at various convenient places where a boosting charge can be obtained through a 6d.- or even 1d.-in-the-slot meter; these pillars would of course be only used for short emergency charges. When charging plugs and battery voltages are standardized, any type of vehicle will be able to charge from these pillars, and the distressing sight of a "run-out" vehicle being towed home would then be avoided. The question of the cost of running is not an easy one to determine, depending as it does on many points unconnected with the actual car. The two heaviest items are the wages of the drivers and the cost of battery renewals; but both can be considerably reduced by using a battery of much greater mechanical strength than the lead battery, in other words, one that can be abused and is practically fool-proof, since renewals would then be kept very low and a cheaper class of driver, for commercial vehicles at any rate, could be employed. With these two items reduced, with solid or semi-solid tyres employed, with a cheap and simple garage, and with labour reduced to a minimum, the total cost per mile should certainly not exceed 8d., and could possibly be brought lower than that. Referring to the very small advance made in the batteries for road vehicles, a company with which I was associated ran in 1897 a 4-seated car to Brighton on one charge; the battery was filled up during the night and the car ran back to London on the one charge next day. This was a performance which would not be bad at the present day, and was certainly very good then. I had the privilege a year or two later of taking this same car to New York, where the car was run for 76 miles on one charge, the battery still having some energy left in it. This battery had previously run hundreds of miles in England, was sent over to America dry, and was charged up again in New York. Both batteries mentioned above were of the Leitner type. Certainly the history of the electric battery vehicle in England is not a very happy one, but what can be done in America should be possible, under proper organization, here, although in all probability the pleasure vehicles will not attain the same degree of popularity. For light delivery vans, however, there is an immense field. Mr. Ayton is very enthusiastic on this subject, the Edison Battery Company, of course, is equally so, and several central-station engineers are showing a practical and valuable example in running electric vehicles in connection with their business. It seems therefore that the electric vehicle may even yet have a good time coming, but events must move quickly, as the petrol vehicle has been allowed to get so well established that it will be very uphill work ousting it from positions for which the electric vehicle is in every way better adapted.

Mr. Warrilow. Mr. W. E. WARRILOW (*communicated*): When it is considered that the electric vehicle industry has made several false starts in this country, it is not surprising that considerable prejudice and suspicion have arisen around electric battery transport. One of the first tasks of those who are at present engaged in the business must be to remove the causes of this feeling of uneasiness before they can set about placing the movement upon a permanent footing in the world of practical automobilism. The early failures with the electric battery vehicle undoubtedly scared capital away from this class of manufacturing enterprise, and mechanical road traction became identified with the internal-combustion engine. I think it is safe to assume that the rise of the petrol vehicle industry will serve to strengthen the hopes of present-day commercial and industrial vehicle users that a more simple, reliable, and efficient machine will soon be at their disposal. Petrol-car engineering has also rendered a distinct service to the simple electric vehicle by introducing gears and gear-cutting machines of the highest accuracy; such accessories contribute largely to the efficient running of an electric battery vehicle. In order that financial interest may again be aroused in the battery vehicle in this country, practical evidence must be given of its efficiency and reliability. We may then expect that the necessary capital will be forthcoming, and that manufacturing concerns will be established. At the present time I think it is desirable that those interested should consider and act

upon the facts as they find them. There are at present some half-dozen agents for Continental and American vehicles offering their machines for the British market. Assuming that the demand is a large one the supply is unlikely to be equal to it for some time to come. In these circumstances it seems to me that the principal thing to do is to follow Mr. Ayton's recommendation to make known as widely as possible the many advantages of the electric vehicle. A number of central-station engineers are withholding their support from every phase of the movement because they believe that they can do no good without actual demonstrations or a car of their own in service. This policy may have something to recommend it, but at the present rate of progress it seems likely that engineers will have to take their turn in a waiting list both for demonstrations and the delivery of the actual vehicles. It is, however, satisfactory to note that for the first time electric-battery-vehicle makers and central-station engineers have come together upon this important proposition. But it seems to me desirable that the station engineer should avoid a policy of waiting upon the vehicle maker to arouse interest within his area of supply. Quite aside from the fact that, as I have already said, there is a difficulty in obtaining vehicles for demonstration purposes, the makers argue that after they have sold a vehicle it is the central-station engineer who becomes permanently and financially interested in it. For this reason, then, it is not unreasonable that the vehicle maker should expect a full measure of co-operation from the central-station engineer. Another matter I should like to refer to is the possibility of the municipal central-station engineer using his direct influence with the heads of those departments that are interested in the electric vehicle from a public service point of view. The borough surveyor, the sanitary inspector, and also the tramways manager, are likely to act upon his recommendation in a matter of this kind. I refer specifically to this because it sometimes happens that the relations between the electricity department and the other branches of the municipality are somewhat strained. The electric vehicle should therefore provide an excellent excuse for breaking down these barriers where they exist. Again, it would be advantageous if one or other of the makers who have dust-carts and similar public service vehicles at their disposal would place one at the disposal of a corporate body having a fleet of steam or petrol wagons; the electric vehicle could then be run side by side with its rivals for a period of, say, 12 months and a practical comparison made between them. It is not sufficient for the vehicle maker to show photos and data of the performance of his machines on the Continent or in America. Many municipal engineers in this country have a penchant for the steam or petrol wagon, and until they have data from British experience they are likely to be slow to move in this matter. In conclusion, I should like to enter an appeal to vehicle makers and central-station engineers to avoid sensational or exaggerated statements regarding the battery vehicle. The movement was undoubtedly checked by this policy in the early days.

Mr. Harding.

Mr. F. J. HARDING (*communicated*): During the past seven years I have had charge of the steam and petrol delivery vans of a well-known London firm, and during the last nine months also of a 10-cwt. Edison-battery van, which is now doing the round of a petrol car. The principal points raised in the discussion refer to lead batteries, and unless one has actually used the Edison battery it is impossible to form any idea of its simplicity and reliability, and the small amount of attention that it requires as compared with the lead battery. Lead batteries must not be charged too fast or too slowly, or allowed to run down and be left standing, or to be overcharged; a short circuit would ruin them, and there is also sulphating, acid-creeping, and the renewal of plates every 3,000 miles. These troubles seem to have been overcome by the Edison battery. All the attention necessary is the addition of a small amount of pure water once a month. The great advantage of this type of battery is the short time that is required for charging, since it does not suffer if charged at 70 amperes or more. It can at any time be plugged direct on to a 110-volt circuit without any resistance, whether it is half charged, one-quarter charged, or empty. The repair and upkeep are very small compared with that of steam- or petrol-driven vans, as the modern electric motor is so constructed as to take almost any load and to run without attention for six months, then only requiring a little grease in the bearings; there is thus a great saving of oil. This van has been doing for the last nine months two deliveries a day, each delivery including 30 to 40 calls, and it has not once been out of commission. During that period it has covered 7,500 miles, and has taken from the mains 3,000 units, which represents ½d. per mile, as against a petrol consumption of 1/10th gallon per mile, *i.e.* a cost of 1½d. per mile, in the case of a petrol van doing the same delivery. I hope that the engineers in charge of generating stations will encourage prospective buyers by keeping the tariff as low as possible. I am sure that in the near future they will reap a good harvest, since a charge would be taken first thing in the morning and at midday, when there is very little other demand for electrical energy.

Mr. Rankin.

Mr. R. RANKIN (*communicated*): In his introductory remarks Mr. Ayton says that we must educate the public. The principal point on which the public will need educating is the care and treatment of the batteries. This is indeed a most important matter if the electric battery vehicle is to be a success. Central-station authorities themselves are frequently not perfect in this respect, and it is scarcely surprising that storage batteries that have to be attended to by chauffeurs sometimes do not come up to expectations. I propose to deal with the case of lead cells, the limitations of which, as regards capacity, must be realized if such cells are to be a success for this class of work. Mr. Brazil has referred to this point and, as he says, any instrument that can be devised to indicate reasonably approximately the state of a battery which is working on varying rates will be a boon in the battery-car equipment. Such an instrument would of course be very valuable in station working, but in car work it would have to be smaller than in the former case, and as compact and easily readable as it is possible to make it. The following are a few details of an instrument that I have devised for this class of work and which is in satisfactory everyday use. Its visible moving members are two pointers which move over the same scale—a scale graduated in volts per cell. One pointer indicates the final permissible potential difference corresponding to whatever current is flowing at any time. The other points to the actual potential differ-

Rankin. Mr Rankin.

ence at that particular time. When the two pointers coincide the battery has reached the limit of its capacity for the particular current then prevailing. If this is a low current the battery is empty; if a high one, more capacity can be obtained from the cells if they are allowed to recuperate. The main value of the instrument lies in the fact that the driver of a car has always before him a true picture of the actual state of the cells at any moment and can, by the exercise of a little common sense, prevent over-discharging and consequent damage to the cells. When

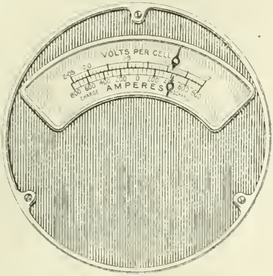

FIG. 4.

he sees the actual voltage of the cells approaching the permissible final value he can slow up his car and give the cells—so to speak—a new lease of life; and this can be done until the battery is empty, the very last ampere-hour being obtainable from the cells without any danger of damaging them. It is reasonable, in battery-car cells, to make the permissible final potential difference proportional to the value of the discharge current, and this being so, the picture of the battery's condition, as shown by the instrument, can be made absolutely clear by marking on the scale of permissible final voltages, the currents corresponding to those final potential differences, the scale in this case being a uniformly graduated one, in fact, the ordinary moving-coil instrument scale. The instrument can be provided with alarm or recorder features, but in the case of car batteries those would hardly be required. Fig. 4 represents an instrument which is in use in an electric supply station and is provided with an alarm. In this form it is practically an ordinary 8-in. dial moving-coil instrument, but somewhat deeper. The final potential differences were arranged to be directly proportional to the currents, and hence the currents were marked on the inside of the volt scale. The upper pointer indicates actual and the lower permissible final potential differences. It should be observed that to the left hand of the zero point in the current scale the voltages are not final values. As has been mentioned, the inclusion of the current values was a side issue, and the volt scale was made to cover the full range from open circuit to the final potential difference at the 1-hour rate. The part of the volt scale to the left of the zero-current point is not so valuable as the remainder when working, although of course the instrument can be made to act on charge as well as on discharge. It should be observed that in ordinary car work the ampere scale would be a valuable feature on the long scale of an 8-in. dial instrument, the calibration being made to suit the actual values obtained in running, and that both the volts per cell and the total voltage of the battery can be indicated on one scale. The driver can therefore have before him in one instrument:—(1) Total battery voltage; (2) actual voltage per cell; (3) permissible final voltage per cell; (4) actual value of the current. For car working, the instrument without its alarm and recording features is smaller than that illustrated and takes up less room than the ordinary combined voltmeter and ammeter. It is, in my opinion, in the direction of improved methods of handling batteries that we must look, for the lead battery when properly treated is really a most valuable and reliable piece of apparatus. Were such an instrument as I have described installed with every battery, whether in a power station or sub-station, or in a battery vehicle, and due regard were paid to its indications, I do not hesitate to say that in many cases the length of life of a battery would be increased by 100 per cent, to the lasting benefit of both battery users and battery makers.

BIRMINGHAM LOCAL SECTION, 18TH MARCH, 1914.

Mr. Chattock.

Mr. R. A. CHATTOCK: The importance to the electrical industry of the introduction of electric battery vehicles into this country cannot be over-estimated. The Incorporated Municipal Electrical Association has formed a Committee with the idea of standardizing as far as possible the apparatus required and the conditions under which vehicles will operate. It is proposed to deal with such points as the following:—Overall dimensions of batteries and number of cells; charging outfits and plugs; voltages; sizes of motors; methods of control, etc. The proposed charges for current are also under consideration by this Committee and it is hoped to standardize them in all parts of the United Kingdom. Ideas vary very much on this point, prices from ½d. to 2d. per unit and over being suggested. My opinion is that 1d. per unit should be satisfactory to all parties, with a possible reduction at night-time. From information available as to what has been done in America and on the Continent, it is known that a big demand for these vehicles can be created if they are properly brought to the notice of the public. They will be specially serviceable for carriers of heavy goods, such as railway companies, for the delivery vans of large shopkeepers, for public services such as street cleansing, watering, and dust collecting, and for motor omnibuses. A service of the latter has been running for some years at Brighton and is apparently giving great satisfaction, whilst the Southend-on-Sea Corporation have now, I understand, purchased one or two vehicles for experimental purposes. Delivery vans and lorries of from ½ to 5 tons' capacity seem to be at the present time the most suitable vehicles for adaptation to electric driving. A 5-ton lorry should produce a revenue of about £80 per annum, with energy at 1d. per unit. It may be concluded, therefore, that a large revenue may be expected by the electricity supply depart-

Mr. Chattock.

ment if these vehicles come into general use. There is no doubt, however, that the public must be educated in this connection before it will recognize the usefulness of such vehicles, and this process will cost money. Manufacturers must be prepared to demonstrate the use of the vehicles in all large towns and to state figures as to the cost of operation which will be convincing to the prospective buyer. The existing garage proprietors, whose interests are at present bound up with petrol-driven vehicles, will not go out of their way to incur expense in dealing with this new branch of the industry unless they are satisfied that by doing so they will eventually be repaid. They are not therefore likely in the first place to provide facilities for charging the vehicles. I suggest that electricity supply stations can give initial help by arranging charging facilities for these vehicles at the stations and sub-stations, although I consider that they should not provide garages permanently for this purpose. Assistance so given in the early stages of the movement will undoubtedly have a very stimulating effect on the use of the vehicles. There will apparently be great competition between the lead and the nickel batteries. Experience can only show which will prove to be the best for the purpose. Meanwhile both are being largely used in America. The battery is that part of the vehicle about which the greatest doubt appears to exist in the mind of the user, and in order to circumvent this I suggest that the makers should be prepared to give reasonable maintenance guarantees over as long a period as possible. It is only by reducing the guarantee charges to a minimum that battery makers can assist in the pioneering work that will have to be done in this country before the public can be convinced of the great utility of the electric battery vehicle. In reply to certain points that have been raised, I may say that the charge of 1d. per unit that I suggest is for current at the standard supply voltage of the undertaking. Motor-generators will undoubtedly have to be used to transform this voltage down to pressures suitable for the batteries. I consider it is very necessary to go into the question of standardization at once. Especially is this the case as regards the standard charging plug and receptacle. It would be a great mistake to allow numerous forms of plugs to be put on the market and to come into general use if this can possibly be avoided.

Mr. Allen.

Mr. S. T. ALLEN: I have been most interested to hear of the work of the Electric Vehicle Committee, from which I received some little time ago a list of questions asking me, amongst other things, what I proposed to charge in Wolverhampton for electricity supply for battery-charging purposes in private garages (1) during peak time, (2) at off-peak times. I should like to ask Mr. Chattock what the committee meant exactly by "peak time" in this case. This appears to me to be important, as what might be considered to be the peak time when supplying direct at the works would not necessarily be the peak time for the purposes of charging at private-house garages. For instance, if a lower charge were made for off-peak supply, and the central-station peak times, say from 3 p.m. until 6 p.m., were taken to determine this, it would hardly be right to allow private householders to commence taking a supply for charging purposes at, say, 7.30 p.m. at the lower rate for off-peak time supply. The peak time in an ordinary residential street, where cooking and heating operations are carried on, is about 7.30 p.m., when the maximum load on the mains on such a street is experienced. The addition of a load of 250 amperes, due to the charging of half a dozen or a dozen car batteries at such a time would probably entail increasing the size of the mains and services in that street by 100 per cent, and it is therefore obvious that the off-peak time at the generating station should not always be the time at which current could be supplied to private garages at a lower rate.

Mr. Fennell.

Mr. W. FENNELL: I note that a committee has been formed by the Incorporated Municipal Electrical Association to promote the adoption of electric vehicles; but if the Institution had taken up this matter it would have been possible to have formed a strong committee of its members which would be representative of all branches of the industry. There is, however, still one field open for the Institution, and it is to be hoped that full advantage will be taken of it. I believe that for about 10 years no important papers have been read on electric accumulators as applied to traction or on the construction or performances of electric battery vehicles. Signal service can be rendered to this branch of electrical engineering by arranging for a series of papers dealing with the details of the construction and rating of electric battery vehicles, so that every electrical engineer will be in a position to speak with certainty whenever the occasion offers, and thereby to inspire confidence in the minds of prospective users. With regard to the question of a standard price, I agree with Mr. Chattock that this is desirable, but I think it would be more advisable to make this standard price the one to be charged to the user for the energy at the standard continuous-current voltage which will be fixed for electric vehicle charging. Simplicity is the great thing to be aimed at in dealing with the non-technical public, who know nothing about peak-load times and will be attracted by a certain reasonable price which they can check against their mileage rather than by a doubtful and varying cost which may be lower on the average. If a charge is made to the user based on the amount of energy supplied at the supply authority's terminals, the user will require information as to the efficiency of the transforming apparatus, and this will vary in different cases, so that the object of standardization will be lost so far as it concerns the vehicle owner. If I were asked to suggest a price I would say $1\frac{1}{2}$d. per unit for all energy supplied to the battery, this price to cover all the costs of providing the supply at the standard continuous-current voltage. The supply authorities could then bargain with the owners of the charging machinery to provide the supply at such a price that the authorities could profitably sell at the standard rate. I agree that the charging business will rapidly pass out of the hands of the supply authorities, and if my suggestion is adopted it will allow a very large margin at the outset to those authorities who do the pioneer work, as they will secure both profits.

Mr. Mitchell.

Mr. R. J. MITCHELL: Mr. Chattock's remarks on the tariff appear exactly to sum up the situation from the station engineer's standpoint. Whilst the cost of energy bears a small ratio to the other costs involved in operating an electric vehicle, it is nevertheless greatly to be desired that a charge as reasonable and as uniformly low as is commercially possible should become the rule. I would suggest that 1d. per unit should be the standard maximum charge, and that wherever possible this should be reduced. An

analysis of the prices charged for energy in 91 cities of America gives an average figure of 3 cents per kilowatt-hour at the station garages. Taking into account the different values of English and American money, this figure would correspond to less than 1d. per unit in this country. Fuel economy affords such an excellent proposition, is such a valuable advertising feature, and, moreover, will be the means of such a large proportion of probable users taking advantage of this feature of the electric vehicle—the fuel aspect being the only one that the uninitiated can understand without explanation—that there seems even more justification for extending the lowest rates to the electric vehicle user than are held out to the domestic user of electrical energy. Yet this latter type of consumer is now supplied at rates cheaper than consumers of electrical energy 10 years ago would have imagined to be possible. A speaker has declared that the battery makers are liable to criticism in that they do not place at the disposal of engineers exact information as to the rating of their products, nor did it seem possible, this speaker declared, to gauge whether any real improvements had taken place in accumulators during the last 10 years. Speaking in support of the Edison accumulator—and leaving the lead type of cell out of the question for the moment—I should like to point out that these strictures apply by no means in this instance. In 1903 Mr. Hibbert read a paper on the so-called E-type Edison accumulator. This type was really a great disappointment to Mr. Edison, who had hoped for far better results than the E-type cell gave in actual service. Nevertheless, the E-type cell was used on quite an extensive scale in the United States, and gave, on an average, $3\frac{1}{2}$ years' service in vehicle operation before depreciating to 65 per cent of its original rated capacity. Many users of this cell refused to sell their batteries back to Mr. Edison, who wished to repurchase as many accumulators as possible in order to keep them in stock for experimental work. The Adams Express Company, a very large transport company in the States, had in operation 200 trucks thus equipped, and obtained an average life of over three years from each of them. The present-day type of cell was introduced in 1909, and in 1912 the same company equipped 88 trucks with it. As an example of the great superiority of the modern (A-type) Edison cell, it is interesting to refer to an endurance test that was conducted in order to compare the two products. When subjected to a process of charging and discharging at very high rates, conducted at a very high temperature of the electrolyte—a combination of conditions well known to be very destructive—the E-type cell depreciated to 65 per cent of its rated capacity after 200 cycles of treatment, whereas the A-type, when treated similarly indicated 4 per cent above its rated capacity after 1,100 cycles; hence it may be inferred that the A-type cell will very far outlive its guarantee period of four years, during which time it is warranted to give 100 per cent of its rated output. As to its electrical characteristics, these are available to any engineer who asks for them. It is, however, useful to remember that on an average the Edison cell may be relied upon to give 12 watt-hours per pound of complete assembled battery at the discharge rates ordinarily met with in vehicle service. I should like to touch on the matter of road resistance. It will be apparent to any engineer that the rating of an electric vehicle in point of distance and speed is entirely dependent on average tractive resistance, occasioned by the particular condition of the road surface over which the vehicle will generally run. Some years ago investigations bearing on this subject were commenced in a systematic manner, but were for certain reasons abandoned. The advent of the electric vehicle induces in itself a very strong plea for the continuation of this research, and I would suggest that our colleges should assign to some of their research students the duty of making reasonably complete accelerometer measurements of tractive resistance per ton over various road-surfaces in the immediate neighbourhood of each college. A relatively small amount of such field-work, which could be done in a few weeks by co-ordinated effort, would result in our having very much more accurate notions of tractive resistance than have hitherto been available.

Mr. A. C. SOUTTER: Mr. Fennell has raised the question as to what improvements have been made in accumulators for use in road vehicles in recent years, and I presume that he refers to the lead accumulator. The lead cell now used for this class of work is an entirely different article from that used for the purpose several years ago, and as a proof of its reliability to-day I think I can do no better than to refer to its successful use on the Brighton omnibuses during the past six or seven years.

Mr. S. H. BILL: I should like to say a few words from the vehicle user's point of view. My firm runs a fleet of about 20 petrol vehicles, and as electricity is generated as a by-product at less than $\frac{1}{4}$d. per unit, I am under the impression that so far as electrical vehicles are concerned my firm should be in a much more favourable position than the majority of users, but my difficulty has always been in getting any reliable data that would be guaranteed by the battery manufacturers. Our petrol costs are from 3·88d. to 5·33d. per ton-mile with 4-ton lorries, this including the wages of one driver and two draymen, garage costs, renewals, insurances, licences, and stores, together with 20 per cent depreciation and 5 per cent interest on the capital. Even at these low figures it is found to be impossible to compete with horse-drawn vehicles on journeys of less than five miles, so that I cannot agree with Mr. Ayton that this form of traffic is likely to be removed from our streets for some considerable time. One of the disadvantages of electric vehicles is their very great weight, necessitating very heavy tyres and springs. I would suggest that the Electric Vehicle Committee consider the advisability of including a vehicle user on the Committee. Although I believe that the battery vehicle will eventually become common, I think it will not be in the immediate future.

Mr. E. STUBBS: In my opinion one of the greatest difficulties in the way of introducing electric vehicles is their first cost, something over £600 being given as the cost of a small delivery van. Few firms can be expected to face such an expenditure. The battery makers are likely to gain quite as much as the supply authorities by the introduction of this system of transport, and I therefore think they should be prepared to supply vehicles and maintain the batteries either for a fixed charge per annum or for a fixed charge per mile. In many towns one or other of the battery makers have contracts for maintaining central-station batteries and have therefore the staff already available to undertake this work. The actual cost of the supply for charging purposes

Mr. Stubbs. is relatively unimportant, as from the figures given for the cost of energy this is a very small proportion of the total cost of running these vehicles.

Mr. Taylor. Mr. A. M. TAYLOR: The points on which we are all desirous of information are the capital cost and the cost of maintenance of the storage battery as applied to electric traction. In order to fix ideas, I have taken records of a certain pleasure car suitable for seating two people and capable of carrying about one ton of luggage. This car is equipped with 50 cells, giving a discharge capacity of approximately 225 ampere-hours at 60 volts. In order to ascertain the cost of the battery, I have assumed that cells as catalogued by an English maker are installed on the car and of such a size that they can give any equivalent discharge to the existing cells. The cost of such a battery, allowing for the usual discount off the maker's list, would be approximately £44; but in order to make the comparison in the case of the more expensive batteries on the market, which would probably have a longer life, let us assume that this cost is increased by 50 per cent, to £66. The question then arises as to what mileage may be obtained with such a battery before it has to be renewed. From numerous records in the United States it would appear that 15,000 miles is a moderately safe estimate. In fact, a certain battery that had been used for two years on a heavy truck which had during that period run a distance of 17,000 miles, was stated to be actually in better condition than at first, and was probably good for another 17,000 miles. Taking, then, this figure for the battery considered above, and the capital outlay at £66, the cost of battery renewals represents only 1d. per mile. This, of course, is a battery for a very light vehicle weighing only 1 ton; and on a vehicle of which the gross weight was, say, 5 tons, it would presumably be reasonable to assume that the cost of battery renewals would be five times this amount, or 5d. per mile. It would seem from this that if the life of a battery can be assumed to be 15,000 miles, the cost of repairs is not at all exceptional, even for a battery costing initially 50 per cent more than a leading English maker's cells. On the other hand I believe it is generally known that the life of a well-known Continental cell has been mentioned as only about 3,500 miles, and that even then its capacity decreased about 60 per cent before renewal. Next, as to the cost of the energy required for the above car, careful records show that 542 miles were covered at an expenditure of energy of 108 kilowatt-hours put into the battery. This, therefore, includes all battery losses, etc., and represents 0·2 kilowatt-hour per mile; and since the car weighs approximately one ton, it is equivalent to approximately 0·2 kilowatt-hour per ton-mile. Now a rough calculation of the amount of energy required for a car on which the tractive resistance averaged 80 lb. per ton and the speed averaged 12 miles per hour, comes to approximately 0·2 kilowatt-hour per ton-mile; adding 50 per cent for the loss in the battery, this would mean 0·3 kilowatt-hour per ton-mile. Now since the car considered above averaged only 0·2 kilowatt-hour and weighed approximately one ton, it would appear as though the average tractive resistance were only, in this particular case, about 53 lb. per ton. This is only a very approximate figure, but it is interesting as so many estimates of tractive resistance have been made, varying from 20 up to 100 lb. per ton. Of course the average figure is materially altered if any important inclines have to be taken into account. It is also interesting to note that at the above figure, viz. 0·2 kilowatt-hour per mile, the cost of energy at 1d. per unit is only $\frac{1}{5}$d. This again would increase approximately in proportion to the weight of the car, and therefore on a car with a gross weight of five tons it would be roughly 1d. per mile. This, however, would be quite a reasonable figure. It would appear from numerous records taken in Indianapolis, where there have been a large number of one-ton lorries (*i.e.* lorries capable of carrying a load of one ton), that these take on an average about $\frac{2}{3}$ kilowatt-hour per mile run, and run some 11,000 to 15,000 miles under all sorts of conditions, in some cases through 14 in. of snow and mud, before the battery requires renewing. Some speakers have complained that the battery companies do not publish any tests or records, but I must say that at least one battery company has published very elaborate tests of the performances of its cells under all sorts of conditions, and tests which have in most cases been verified many times. One of these tests showed that on allowing a fully charged battery to stand idle for 10 days the charge had only decreased by about 10 per cent. In another test a cell was allowed to stand for six months completely discharged, its performance at the end of that time, after recharging, being practically the same as at the beginning of the test. In another case a cell was heated to 130° F. and then short-circuited until completely empty. This process was repeated about 500 times, and it was found that even after such treatment the cell had as great a capacity as at the commencement of the test, and that after the first 150 or 200 such discharges its capacity had actually increased. It was also found that even after 1,000 such discharges the cell had only lost 20 per cent of its original capacity. If we allow 30 miles per charge, 500 charges would represent 15,000 miles, and 1,000 charges 30,000 miles run; and as the above treatment is far worse than any that is likely to occur in practice, it would seem quite safe to assume that the figure which I took for the life of a battery, viz. 15,000 miles, is a reasonable estimate for this class of cell. Reference has already been made to tests in which three cells, after having been used for 17,000 miles on a one-ton delivery van, were found to give a 34 per cent better performance than when originally installed. These three cells were selected at random out of a group of cells. In view of tests such as these it seems incorrect to say that the battery makers have not published the results of tests on their cells.

CURRENT-LIMITING REACTANCES ON LARGE POWER SYSTEMS.

By K. M. FAYE-HANSEN, Associate Member, and J. S. PECK, Member.

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One of the most striking developments in connection with the supply of electrical energy is the rapid rate at which generating stations and generating units are increasing in size. This increase is due not only to the more general use of electricity for lighting and for domestic purposes, but to the fact that large manufacturing firms, tramways, railways, and other large employers of labour, are finding it cheaper to purchase electrical energy than to generate it in their own power stations. Thus an ever-increasing proportion of the community is becoming dependent upon the continuity of supply from these stations and the time is fast approaching when a serious disaster to a large supply station may pass from a mere inconvenience to a civic calamity. On account of their size, however, these large stations have a power of causing internal and external damage quite beyond that possessed by a station of small or moderate size; it is therefore incumbent upon their designers not only to use every means to prevent accidents, but to make such provision that, if accidents do occur, the amount of damage shall be reduced to a minimum and the trouble confined to the particular section of the plant where it occurs. To accomplish these results current-limiting reactances are being extensively adopted, and it is proposed in the present paper to discuss their operation, to indicate where they may be placed, and the sizes which should be used in the different positions, in order most satisfactorily to accomplish the desired results under various conditions. In the latter part of the paper the design of the reactance coils themselves will be considered, and the relative merits of coils with air cores and with iron cores will be pointed out.

It is well known that a generator which will give but two or three times full-load current on sustained short-circuit may give 20 to 40 times full-load current at the instant of short-circuit. This is due to the fact that the armature reaction requires time to assert itself, so that the first rush is limited only by the reactance of the armature circuit. If the armature of the generator has 5 per cent reactance, 20 times normal current may flow at short-circuit, and if an additional 5 per cent is inserted in the form of choke coils, the instantaneous rush is limited to 10 times normal. These values may, however, be increased owing to the so-called "doubling effect." *

The general effect produced by a series reactance is a drop in voltage in the circuit, provided the power factor is unity or lagging; and the greater the lag the greater is the drop in voltage. The power factor is also decreased on account of the reactive kilovolt-amperes of the choke coil. It may be stated that the number of kilovolt-amperes at zero power factor is increased by the kilovolt-amperes of the reactance coil. This is but another way of saying that the wattless kilovolt-amperes of the choke coil may be added arithmetically to the other wattless k.v.a. components of the circuit in order to give the total wattless kilovolt-amperes. Thus it is evident that the introduction of reactance affects the regulation and power factor of the system; and these are two of the factors which determine the sizes that should be placed in generator leads or feeders.

LOCATION OF REACTANCE COILS.

In general, reactance coils may be placed in any one or more of the following positions :—

1. In the generator leads.
2. In the feeders.
3. Between sections of the busbars.

In the various positions their effect upon the following should be considered :—

(*a*) Generators.
(*b*) Circuit-breakers.
(*c*) Voltage of supply.
(*d*) Continuity of service.

The different conditions of operation to be considered are :—

(*a*) Normal operation.
(*b*) Short-circuit on feeder.
(*c*) Short-circuit on busbars.
(*d*) Short-circuit on generator.

1. REACTANCE IN GENERATOR LEADS.

Fig. 1 is a one-line diagram showing six generators connected through reactance coils and circuit-breakers to a common busbar. In normal operation the reactances will produce a drop in voltage between the generators and the busbars; but this can readily be compensated for by varying the excitation of the generator. Thus the voltage on all the feeders will be the same, and may be kept constant or may be varied in accordance with the load. The power factor of the load on the generators will be decreased by the reactances, the extent of the reduction depending on the size of the reactances and the load on the busbars.

In the event of a short-circuit upon a feeder as at X, the busbar voltage will drop to zero (provided the impedance of the fault and of the feeder between the fault and the busbars is negligible), and all generators and other synchronous apparatus on the system will feed into the short-circuit. If the system is a very large one, this

* When a pressure is suddenly applied across the terminals of a choke coil or of a transformer, the first rush of current may be far in excess of the normal magnetizing current. The magnitude of this current will depend upon the point of the voltage wave at which the circuit is closed (*Electric Journal*, vol. 5, p. 152, 1908).

current may be enormous and may damage or destroy the circuit-breaker in the defective feeder. It may also cause serious damage at the fault. It should be noted, however, that even on the largest system the current in the event of a fault will be less than it would be without these reactances. The generators should not suffer, because the output of each is limited by the reactance in series with it; and for the same reason the generator circuit-breakers should not be damaged. The worst feature of this arrangement is that, the whole of the busbar being affected, all synchronous apparatus throughout the system may fall out of step and a complete shut-down is likely to occur.

It might be argued that the feeder circuit-breaker should clear the fault before the synchronous apparatus falls out of step, but this is improbable, as the circuit-breaker requires an appreciable time to operate even when set for instantaneous tripping, and it is general practice to set circuit-breakers with a time lag to relieve them from the

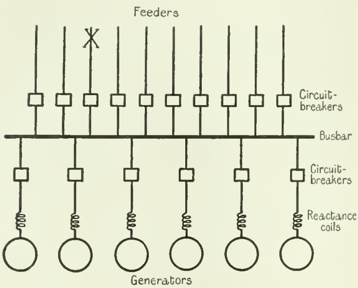

Fig. 1.

duty of breaking the enormous instantaneous rush of current that occurs on short-circuit. However, if the fault occurs at any considerable distance from the generating station, the impedance of the feeder will greatly reduce the current, so that the busbar voltage will drop comparatively little and synchronous apparatus will not fall out of step.

With properly insulated busbars the chances of a short-circuit on them would be almost negligible, but in the event of such a short-circuit occurring, the action will be precisely the same as with a short-circuit on the feeder, except that the feeder circuit-breaker will not suffer.

In the event of a short-circuit on a generator, the armature winding will be distorted if not properly braced; but the current which can flow from the busbars to the defective generator will be limited by the reactance, and the circuit-breaker should be able to disconnect the generator from the busbars without difficulty. Also the voltage of the busbars will not fall to zero, and the operation of synchronous apparatus will probably not be affected; in fact if there are a large number of generators in operation the busbar voltage may decrease very little.

The advantages and disadvantages of placing reactances in the generator leads only may be summarized as follows:—

Advantages of reactance in generator leads:—

1. The busbar voltage may be kept constant, giving the same voltage on all feeders.
2. No damage to the generators in the case of a short-circuit on a feeder or busbar.
3. No damage to the generator circuit-breakers in any case.
4. Synchronous apparatus will not fall out of step in the case of a short-circuit on the generator.

Disadvantages:—

1. Enormous current-rush into a short-circuit on a feeder.
2. Excessive load on the feeder circuit-breaker in the case of a fault on a feeder.
3. Synchronous apparatus may fall out of step, and a complete shut-down may follow a short-circuit on a feeder or busbar.

From what has been said it will be evident that reactances in generator leads alone are of little value except for protecting generator windings and circuit-breakers, as they offer no guarantee of continuity of service except in the case of the breakdown of a generator. Their size will therefore be determined by the robustness of the generators and the circuit-breakers. Assuming that the average generator has a reactance of 6 per cent, and 6 per cent is added in an external coil, the maximum current that can flow equals $8\frac{1}{3}$ times the normal current, or somewhat more than this due to the doubling effect. Any generator should be able to stand a current rush of this magnitude. If the generator has 8 per cent reactance, then 4 per cent in the external coil will limit the current to the same value.

Where a step-up transformer is connected between the generators and busbars, it may be designed with high internal reactance, thus giving the effect of a reactance coil without any appreciable additional cost.

2. Reactance in Feeders.

Fig. 2 shows an arrangement of six generators connected to a common busbar from which several feeders are supplied, each feeder having a reactance coil in series with it. In normal operation each coil will produce a drop in voltage on its feeder, and if some feeders are more heavily loaded than others, the voltage drop on the feeders will vary and cannot be compensated for by varying the busbar voltage. Under certain conditions this may prove troublesome, but when the supply is to synchronous apparatus this voltage difference can be compensated for by varying the power factors of the synchronous machines. These reactances will also reduce the power factor of the load on the generators, though they wil' ᵓt affect the power factor of the feeders beyond the reactances.

In the event of a short-circuit upon a feeder, as at X, the current supplied to the fault will be limited by the re-

actance and the busbar voltage will be affected to only a small extent. The circuit-breaker should be able to cut out the feeder without difficulty, and only the one feeder will be affected. Since the current is limited by the reactance, the generators will not be heavily overloaded, and none of their circuit-breakers should open.

A short-circuit on the busbars will short-circuit all the generators, and if the windings are not properly braced may cause serious damage. Also the whole system will be thrown out of action and each generator circuit-breaker must open the short-circuit current of one generator.

Should a short-circuit occur in the generator windings, the self-induction of the generator windings will usually be sufficient to limit the current until the circuit-breaker has acted and cut out the faulty machine; but should a short-circuit occur between the generator and the circuit-breaker, all the generators would feed into the short-circuit, and the circuit-breaker on the defective generator would have to open the short-circuit current of all the other generators. In this case the voltage of the busbars will drop to zero and all synchronous apparatus may fall out of step so that a complete shut-down is likely to occur. It should be noted, however, that in the case of trouble on the busbars or generators, the feeder reactance will slightly reduce the amount of current that the synchronous apparatus on the system can feed back into the fault.

If the generator windings are braced to withstand short-circuits, this arrangement of reactances possesses marked advantages over that of placing them in the generator leads, for the great majority of faults occur on the feeders or on apparatus connected directly to them; and with feeder reactances such faults can do no serious damage to the system. Furthermore, busbars and connecting cables can be so thoroughly insulated that a short-circuit on them is a somewhat remote possibility. But if the generator windings will not withstand a short-circuit, it would be foolhardy to risk the disablement of the whole generating plant through a busbar or generator short-circuit, even though there is little chance of such a short-circuit occurring.

Advantages of reactance in the feeders.

1. A short-circuit on a feeder causes no serious disturbance on the system, and there is no excessive overload on circuit-breakers or generators.
2. The feeder circuit-breakers may be of smaller breaking capacity than those where feeder reactances are not used.
3. The tendency of synchronous apparatus to feed back in the case of a busbar fault is slightly reduced by the feeder reactances.

Disadvantages.

1. The voltage drop on the feeders will vary with the load and cannot be compensated for by varying the busbar voltage.
2. A short-circuit on the busbar or generators is a short-circuit directly on the terminals of all generators. The generator windings and circuit-breakers may be damaged and the complete plant shut down.
3. A short-circuit on any generator or between any generator and its circuit-breaker may throw an excessive load on this circuit-breaker, and if it fails to clear the fault the whole system will be shut down.

The size of the feeder reactances will depend on the capacity of the feeder, as compared with that of the generators, and upon the breaking capacity of the feeder circuit-breaker. Thus if the rating of a feeder is one-quarter that of a generator, a reactance of 3 per cent in the feeder will pass no more current than will a total reactance of 12 per cent in the generator, while if there are several generators in parallel, the effect of the feeder reactances is proportionally increased. Thus unless the total feeder rating is very greatly in excess of that of the generators, the total k.v.a. capacity of the feeder reactances may be

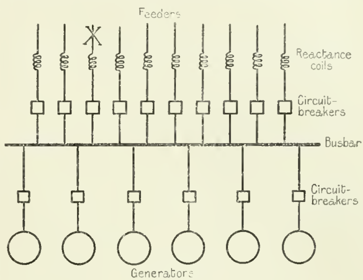

FIG. 2.

less than the k.v.a. capacity of the generator reactances, though the number will in general be much larger. In certain cases it may be desirable to group the feeders and use one set of reactances for the group, thus greatly reducing the number of reactances.

If the feeders are of very great capacity compared with the generators, the feeder reactances must be much larger and their use may not be justified.

Where step-up transformers form part of the feeders, the transformers may be designed with high internal reactance without appreciable increase in cost.

3. Reactances in Busbars.

The action of reactances in series with generators or feeders is easily understood and their effect on the system is readily calculated, but when placed between generators or busbar sections their action is more difficult to understand, and it has been thought best to consider this part of the subject more fully.

The only purpose in installing busbar reactances is to limit the amount of current that can flow into a fault on one section of the busbars, and so to confine the disturbance to that part of the system on which the fault occurs. Viewed from this point only, the greater the reactance the better the result; in fact the purpose would be accom-

plished perfectly by isolating the sections entirely. From economical considerations, however, it is highly desirable to operate all the generators of a station in parallel. As a compromise, reactances are chosen of such a value as to permit parallel operation during normal conditions, even with a considerable exchange of energy between the sections; while in the event of a short-circuit occurring on any section, the current rush is limited to such a value as not seriously to interfere with the operation of other sections.*

In order to obtain some idea as to the angular relations of the currents and voltages in two or more generators separated by a reactance, a few cases will be considered.

Fig. 3 shows two generators A and B supplying a busbar which is divided into two sections by a reactance coil. It is assumed that the voltages on A and B are to be kept equal, that the engine governors are set to give equal loads on the two generators, and that the load on feeder D is twice that on feeder E. It will also be assumed that the loss in the reactance coil can be neglected, so that the pressure across the coil will differ in phase by 90° from the current flowing in the coil.

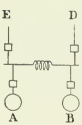

FIG. 3.

FIG. 4.

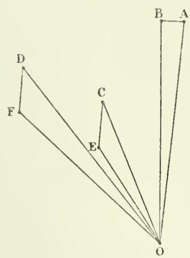

FIG. 5.

Fig. 4 shows the relation between the currents and pressures when the loads on the two busbar sections are at unity power factor.

O A is the voltage on generator A and on its busbar section. O B is the voltage on generator B and on its busbar section. In order that there may be an exchange of energy between the two sections of the busbars, the angular position of the voltages must be different.

A B is the voltage across the reactance coil, and since this differs in phase from the current by 90°, it is obvious that the angular position of the circulating current is midway between the voltages O A and O B.

O D represents the current in feeder D in phase with voltage O B. O E represents the current in feeder E in phase with voltage O A. O D = O E × 2. D F and E C represent the current flowing through the reactance. O C represents the current of generator A. O F represents the current of generator B.

It will be noted that the current through the reactance increases the load on generator A and decreases that on generator B; the two machines are now equally loaded and the current in both generators lags slightly.

A study of the diagram shows that with a given angular displacement between the generator voltage, the amount of current which can flow between the sections is limited by the voltage drop across the reactance. Thus, having decided upon the maximum allowable displacement for parallel operation and the maximum difference in load which is likely to occur between the different sections, the value of the reactance may be determined immediately.

Fig. 5 shows the relations between the current and pressures when the loads on the two busbar sections have each a power factor of 0·8. The generator voltages are equal in value, and the current in feeder D is twice that in feeder E. O A and O B represent the generator voltages as before. O E and O D represent the currents in the two feeders lagging approximately 37° behind the busbar voltages. E C and D F represent the current through the reactance. O C is the current in generator A. O F is the current in generator B.

The projection of O F on O B equals the projection of O C on O A, showing that the energy delivered by the two generators is equal. It will be noted that while the current

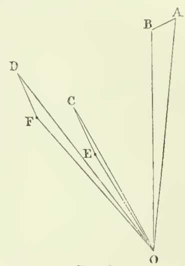

FIG. 6.

flowing through the reactance increases the load on generator A and decreases that on generator B, the power factor of the load on A has been increased and that on generator B decreased.

Fig. 6 shows the same conditions as to loads and power factors as in Fig. 5, but the voltage on generator A is 5 per cent greater than that on generator B. A B is the pressure-drop across the reactance, and the vector of the current through the reactance is at right angles to this voltage. This current is shown at E C and D F, giving generator currents of O C and O F. It will be noted that the value of the circulating current is greater than in Fig. 5, and that the power factor of O C is lower, while that of O F is higher than in the preceding case. It is evident that by increasing O A the power factor of the load on generator B could be improved until it becomes higher than that of the load on feeder D and equal to or higher than that of generator A. This is quite what would be expected from the well-known behaviour of alternators operating in parallel. It is, however, seldom possible to operate in this manner, as it will generally be necessary to keep the different busbar sections at the same potential.

* For a brief consideration of the effect of busbar reactances on parallel operation, see Appendix.

Fig. 7 shows the relations that exist where there are two generators working on one busbar section and one on the other section. There is no load on feeder E, and the load on feeder D has a power factor of 0·8. The voltage on the generators is kept equal in value, and the engine governors are set so that the three generators divide the load equally.

O A and O B are the generator voltages. O D is the current in feeder D. O C is the current supplied by generator A, and in phase position is midway between the voltages O A and O B. D F = O C. O F is the load on the two generators B and B_1, and the projection of O F upon O B equals twice the projection of O C on O A, *i.e.* the energy load on generator A is equal to one-half the energy load on the two generators B and B_1. It is evident that the current O F is greater than twice the current O C since its power factor is much lower.

In order to obtain a concrete idea of the values involved in a specific case, an arrangement will be taken such as is shown in Fig. 8. Eight 10,000-kw. 10,000-volt generators are connected to the busbars, which are divided into two sections by reactance coils. Feeders D supply a load of

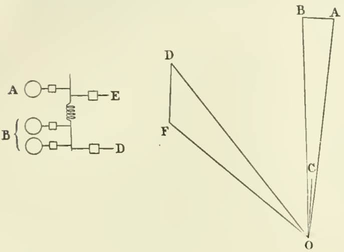

FIG. 7.

60,000 kw. at 0·8 power factor, and feeders E a load of 20,000 kw. at the same power factor. The voltages on D and E are to be kept equal, and all generators are to carry equal kilowatt loads.

It is evident that one group of generators must supply 20,000 kw. to the busbars fed by the other group. Let the reactance coil be of such a size that with the current corresponding to 20,000 kw. flowing through it the voltage across it will be 25 per cent of the normal. The capacity of this reactance = 5,000 k.v.a. 3-phase, or 1,660 k.v.a. for each phase.

Draw O A and O B, making A B = 25 per cent of O A. O D and O E represent the feeder currents laid off to the proper scale, each lagging approximately 37° behind its busbar voltage, O D being three times O E. D F and E C represent the currents through the reactance. O C is then the current supplied by generators A, and O F that supplied by generators B.

Since with a current corresponding to the capacity of two generators the drop across the reactance is 25 per cent of the normal, the maximum current that can pass with full voltage across the coil is that corresponding to the normal current of eight generators, though this may be increased somewhat on account of the doubling effect.

This current is considerably less than a single generator can give at the instant of short-circuit, and is about the same as would be given by one generator after the time interval required for a circuit-breaker to open, so that the effect of the short-circuit would be no more severe than would be the case if there were a total of five generators coupled to one busbar.

In a very large station the busbars would probably be separated into several groups of from 20,000 to 40,000 kw. capacity each. In a case of this kind the amount of energy that it may be necessary to transfer between sections is assumed and the reactances made large enough to limit the current to a reasonable value in case of a short-circuit, but not too large for satisfactory parallel operation. A size that will give 50 per cent of normal voltage with the full-load current of one busbar section is usually a reasonable value to choose.

The use of busbar reactances is carried to the extreme when the busbar is divided by them into as many sections as there are generators. Fig. 9 shows an arrangement of this kind where there are eight generators and eight reactances. It is assumed that each generator is of 10,000 kw. capacity, that the load on the D feeders is 60,000 kw., and that on the E feeders 20,000 kw. Then if all generators are to be equally loaded the A group must supply 20,000 kw. to the D feeders.

Assume that all E feeders are equally loaded and that all the D feeders are equally loaded. Then through R_4 and R_8 must pass 10,000 kw., and through R_1, R_3, R_5, and R_7 5,000 kw. Since the busbar units are small, and it may be necessary to transfer energy through two or more reactances in series, they should be made smaller than where the busbar sections are larger in size but fewer in number.

Assume the voltage across reactances R_4 and R_8 to be 25 per cent of the normal, corresponding to an angular displacement of voltage of approximately 15°. The voltage across reactance R_1, R_3, R_5, and R_7 will be 12·5 per cent, corresponding to an angular displacement of approximately $7\frac{1}{2}$°. Fig. 9 shows the voltage relations that exist between the different generators. It is improbable that the load on any busbar section will greatly exceed the capacity of the generator connected to that section, so that the conditions given above are as severe as are likely to be experienced in actual service; but even with a considerably more unequal distribution of load there should be no trouble in parallel operation.

Arrangements will always be made for short-circuiting any reactance so that in the event of a generator being shut down the feeders connected to its busbar section may be supplied directly from one of the adjacent generators. Arrangements must also be made for opening the busbars between any two generators in order to isolate any section of the busbars that might develop a fault.

With the arrangement shown in Fig. 9 assume that a short-circuit occurs on the busbar section supplied by B_4. The voltage on this generator would fall to zero, and it would supply maximum current into the fault. If the voltage on A_1 and B_3 kept up to normal for an instant, each of them would feed into the short-circuit four times normal current; but on account of the reactance in each armature circuit, which may be taken at say 5 per cent, the

current would be $100/(25+5)=3 \cdot 3$ times normal, and would drop quickly to a much lower value. The voltage at the same time would drop to perhaps 50 per cent of the normal.

As soon as the voltage on A_1 and B_3 begins to fall, generators A_2 and B_2 start to supply current through reactances R_1 and R_5. These currents would reduce to a slight extent the voltages on A_2 and B_2, but would tend to raise the voltage on A_1 and B_3. Similarly, A_3 and B_1 would tend to supply current through reactances R_2 and R_5 as soon as the voltages on A_2 and B_2 begin to fall. The effect, however, on the voltage of these generators would be practically negligible.

To determine definitely the voltage on each generator and the current flowing through each reactance is a

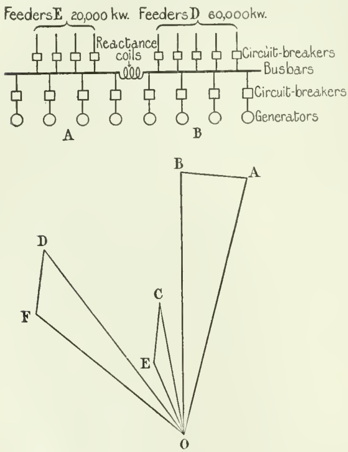

FIG. 8.

somewhat complicated problem, and requires definite data as to the characteristics of each generator, but sufficient has been said to indicate the general effect of the reactances in limiting the rush of current and the damage that can be done.

Another advantage of using reactances between each generator is that it greatly reduces the chances of damaging a generator in the event of a mis-phase, a feature of considerable importance.

Advantages of busbar reactances :—

- Trouble is confined to the particular section on which the fault occurs.
- The amount of current that can be fed into a fault is reduced.
- The danger in the case of bad synchronizing is considerably reduced.

Disadvantages :—

- No protection to a generator is given when a short-circuit occurs on or near its busbar section.
- The generators coupled to the different busbar sections must be operated with a certain angular displacement in their voltages.

From what has been said it will be clear that reactances between busbar sections may be exceedingly useful for confining any disturbance on the system to that particular section on which the trouble occurs, and thus it is possible to operate a large number of generators or two or more stations in parallel with almost the same factor of safety against a complete shut-down as though they were

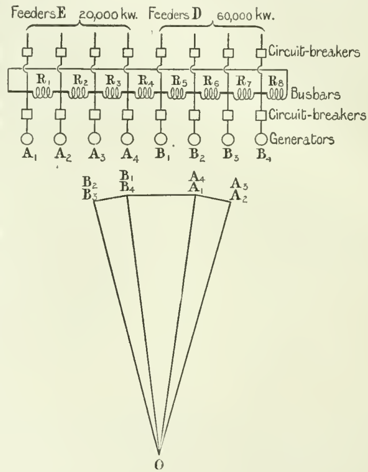

FIG. 9.

operated separately. It is seldom, however, that busbar reactances are used except in conjunction with reactances in generators or feeders, and it is proposed now to discuss very briefly their combined use.

REACTANCES IN GENERATORS AND BUSBARS.

Naturally the size and number of the reactances is the first question to be decided. Since the principal object of the generator reactances is to protect the generator windings, these will naturally be chosen with reference to the characteristics of the generator, and evidently one will be placed in each generator lead. The more completely the busbars are divided up by reactances, the smaller will be the portion of the system affected, and from this point of view reactance is desirable between each generator and the next; but as this may involve

some slight complications in the normal operation of the plant, it may be considered desirable to operate with several generators connected to the same busbar section. The size of the reactances will be determined by the amount of energy that must be transferred from one section to another, and by considerations of successful parallel running.

The advantage of this combination over the use of reactances in generators alone is very great, as it confines the trouble to the particular busbar section affected; it reduces the load on the feeder circuit-breaker, and reduces the damage at the fault. Perfectly satisfactory operation should be obtained with this arrangement.

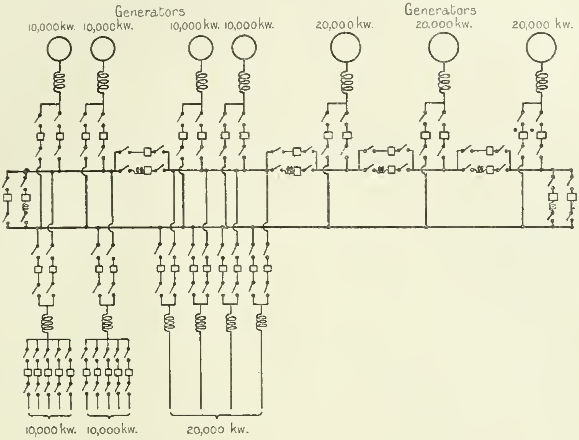

FIG. 10.

Reactances in Feeders and Busbars.

Reactances will be placed in all feeders or alternatively in all feeder groups. Their size will be determined by the capacity of the feeder or group, with reference to the capacity of the busbar section and with reference to the breaking capacity of the circuit-breaker. The number and size of the busbar reactances will be determined as previously specified.

This arrangement probably gives the greatest possible freedom from serious operating troubles, for the feeder reactances protect from all troubles outside the station, while the busbar reactances confine any internal trouble to the busbar section on which it occurs.

The objections are that it affords no protection to the generators in case of a short-circuit on the busbars, that it requires a large number of reactance coils unless group feeding is adopted, and that it affects the regulation of the feeders, though this will ordinarily be of minor importance. If the generators can safely withstand a short-circuit, or if the chance of a short-circuit on the busbars is considered negligible, some form of this arrangement probably offers the most complete solution of the problem.

It has been attempted in the foregoing discussion to indicate the advantages and disadvantages resulting from the use of reactance coils placed in different positions in a power station, but when it is attempted to apply this knowledge to a concrete case there are so many factors to be considered that the determination of the best possible combination becomes a difficult problem. For example, if the busbars are divided into sections by reactance coils, and the different sections feed into the same busbars at one or more sub-stations, the impedance of the cables connecting the different sections may be far less than that of the reactance coils, so that much of the advantage gained by using the reactance coils is lost. Also there is the possibility that when one section is more heavily loaded than another, the cables on one section will be overloaded, due to the angular displacement in voltage between the sections. Thus it is desirable when using busbar reactances to feed one sub-station from one section of the busbars, rather than from several sections, or, failing this, to use fairly large feeder reactances. When the feeders are very long this may not be of importance. When suitable feeder arrangements can be made, there seems no doubt as to the great desirability of using busbar reactances in large stations as an insurance against a complete shutdown.

In the case of feeder reactances, the greatest flexibility is obtained by placing reactances in each feeder; this is quite feasible where the feeders are of large size and comparatively few in number, but where there are many

feeders of small size the number of reactance coils becomes excessive and group feeding must be adopted.

Reactances in generator leads present the simplest problem, once it has been decided to install them. The only difficulty is to determine whether they are necessary in addition to the busbar reactances. The following points should be considered :—

If the generators will stand a short-circuit, reactances serve very little purpose except to protect the system in case of a generator breakdown and to reduce to a small extent the current that flows into a short-circuit. Busbars may be so thoroughly insulated as to reduce the possibility of a short-circuit to almost a negligible amount. It is now becoming fairly common practice to use single-core cable between the generators and busbars. These cables can be so arranged that an "earth" is almost certain to occur before a short-circuit, and a suitable discriminating device will cut off the generator and open its field circuit the instant that an "earth" occurs. Thus the chances of a short-circuit on the generator terminals may be greatly reduced. But there is still the possibility of a mis-phase where more than one generator is connected to the same busbar section; and if the generator will not withstand such an accident it will be advisable to use reactances in its leads.

In order to show a typical lay out for a large station, the following conditions have been assumed :—

Total generator capacity, 100,000 kw.
Seven generators (4 of 10,000 and 3 of 20,000 kw.).
Feeders of 2,000 and 5,000 kw., the 2,000-kw. feeders being arranged in groups of 10,000 kw. each.

A diagram of connections is shown in Fig. 10. In this case, the busbars are divided into five sections of 20,000 kw. each. Each section of the busbar is fed either by one large generator or by two small ones. Between each busbar section is connected a reactance coil, which, with the full-load current of one busbar section, will give a voltage across it equal to 50 per cent of the normal.

Each reactance coil is arranged so that it may be short-circuited by means of an oil circuit-breaker, and an oil circuit-breaker is also placed between sections of the busbars.

A ring busbar system is adopted, which increases considerably the flexibility of the arrangement.

Each group of feeders will have in series with it a reactance coil, which should be of such a size that with the group fully loaded there will be a voltage across it of approximately 5 per cent. Each 5,000-kw. feeder should have in series with it a reactance coil, which will have a full-load voltage across it of approximately 2½ per cent. In series with each generator there should be a reactance of approximately 5 per cent.

It is preferable to have each sub-station fed from one section of the busbars in order that circulating currents may not flow through the cables from one busbar section to another. The ring-main busbars and double set of feeder switches permit any sub-station to be switched over to another section in case of necessity.

Discriminating devices should be provided so that in the event of an "earth" on any feeder it will be cut out. Also each generator should be arranged in a similar manner, so that it will be cut out in the case of an "earth" or other fault developing on it.

In order to give an idea of what will occur in the event of a fault on a system such as that shown in Fig. 10, the values given in the following table have been calculated.

TABLE SHOWING CURRENTS AND VOLTAGES UNDER FAULT CONDITIONS WITH DIFFERENT REACTANCES.

No.	Position of Fault	Reactance Location and Size			Current Times normal of 1 Section		Voltages Percentages of Normal	
		Busbar	Generator	Feeder	Fault	Generator	Faulty Section	Adjacent Sections
		%	%	%				
1	Feeder	0	5	0	100	20	0	0
2	,,	0	10	0	50	10	0	0
3	,,	0	5	5	16·6	3·3	83·3	83·3
4	,,	0	10	5	14·3	2·86	71·5	71·5
5	,,	0	5	10	9·1	1·82	91·0	91·0
6	,,	0	10	10	8·33	1·67	83·3	83·3
7	,,	50	5	0	23·6	20·0	0	91·6
8	,,	50	10	0	13·4	10·0	0	85·4
9	,,	50	5	5	10·8	9·2	54	96·2
10	,,	50	10	5	8·05	6·0	40·2	91·2
11	,,	50	5	10	7·05	5·95	70·5	97·50
12	,,	50	10	10	5·71	4·29	57·1	93·7
13*	Generator	50	10	any	10 + 4·65	10, 2·7 and 0·85	46·5	90·1
14*	,,	0	10	,,	10 + 8·2	10, 1·82	81·8	81·8
15†	,,	0	10	,,	20 + 13·3	20 and 3·3	66·6	66·6
16†	,,	50	10	,,	20 + 2·92	20 and 1·25	14·6	88·2
17	,,	With 5 per cent total reactance (*i.e.* no external reactance in generator leads) the results are the same as for a feeder short-circuit given above with zero feeder reactance.						
18	Busbar	The same results as given above when a short-circuit occurs on a feeder with zero reactance.						

* Two generators feeding one section of busbars. First value under fault current is that supplied by faulty generator. Second value is that supplied by other generators. First value under generator current is that in faulty generator. Other values indicate the current in other generators.

† One generator feeding one section of busbars, otherwise the same as 13 and 14.

This table shows the value of the current that will flow into the fault and in the generators, with different values of reactance in different parts of the system. The busbar voltage is also given for the faulty section, and for the adjacent sections.

In each case, the value of the reactance is expressed as a percentage of the normal voltage, with the full load of one section or of one generator flowing through it.

The current is given in terms of normal rated load of one busbar section, and is the maximum at the instant of short-circuit, neglecting the doubling effect and also neglecting any current that may be regenerated by synchronous apparatus operating on the system. The values of current and voltage will, in general, fall off very rapidly as the armature reaction of the generators asserts itself.

The Design of Current-limiting Reactances.

Current-limiting reactance coils have heretofore been designed almost exclusively without iron in the magnetic circuit. The larger coils have usually been cooled by means of an air blast. On account of the great shocks to which these coils are subjected it is necessary to adopt a very strong mechanical construction, and the winding must be so laminated as to reduce the eddy currents caused by the stray fields. The General Electric Company of America use a winding of stranded cable wound in concentric layers. The core is of concrete, and the different turns and layers of the winding are spaced and held rigidly in position by spacing blocks of porcelain which are bolted together and to the core, thus making an extremely rigid construction. Each coil is usually placed in a cubicle made of bricks or tiles, which acts as a flue for guiding the air blast through the coil and prevents any person from coming in contact with the winding. On account of the heavy stray field outside the coil it is impossible to place it in a metal case, and it is advisable to keep it a considerable distance from any steel structure.

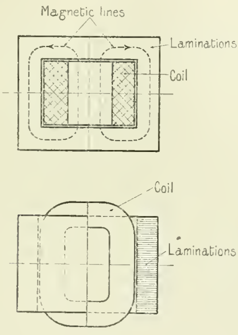

Fig. 11.

The American Westinghouse Company use a winding of stranded cable, but wind a number of pancake cores which are placed side by side. There is no central coil, and the turns and layers are held in position by means of fireproof partitions which are bolted together. This gives a very sound mechanical construction, and is easily adaptable for a wide range of capacities.

The air-core construction has been adopted upon the assumption that it would not be possible to use an iron circuit and obtain a straight line relation between the voltage and current without increasing the size, price, and losses in the coils. While this may be true for feeder reactances where the maximum short-circuit current is perhaps 20 to 30 times the normal current that the coils must carry without overheating, it is not true in the case of busbar reactances where the maximum current will as a rule not be more than 4 to 10 times the normal current, and under certain circumstances the coil with a partial magnetic circuit will prove more economical than the air core even for generator reactances.

The larger the capacity of a reactance coil and the lower the frequency, the less will be the advantage obtained by using iron in the magnetic circuit.

Fig. 11 shows diagrammatically the construction of a choke coil having a partial iron circuit. It will be noted that inside the coil there is no iron, and therefore the air-gap is very large, while the coils are enclosed by a complete iron circuit. This construction has the following advantages compared with air choke-coils :—

1. Under normal working conditions there is no external field, so that the whole coil may be placed in a metal tank without fear of eddy currents, as though it were a transformer.
2. The coil may be operated in oil, thus avoiding the necessity for forced cooling, though the air-blast type can be used if preferred.
3. Less room in the station will be required, as it is possible to place the apparatus in the same position as a transformer and to handle it just as though it were a transformer.
4. The metal containing case may be earthed so that there can be no danger from accidental contact with the coil.
5. It is not essential to use a laminated cable winding, as the direction of the flux is such that a solid winding may be arranged by careful designing to avoid any serious loss.
6. The construction being practically the same as that of a transformer, standard transformer parts may be used to a very great extent, thus reducing development costs and the time required for manufacturing.

APPENDIX.

The Effect of Busbar Reactances on the Parallel Operation of Alternators.

A reactance coil connected between two alternators influences parallel operation in two ways :—

It limits the current that can flow between the two generators.

It necessitates an angular displacement between the voltages of the two generators if there is a transfer of energy through the reactance.

It will be assumed in what follows that the induced voltages of the alternators are equal, that the resistance in circuit between the alternators and in the armatures may be neglected compared with the reactance, and, further, that the alternators are of the non-salient pole type, so that it is allowable to assume the synchronous reactance to be independent of the relative position of the stator and the rotor.

In Fig. 12 O A and O B are the induced voltages of the two alternators which are displaced in position by the angle a, while B A is the vectorial difference between these voltages. This voltage difference will cause a current to flow between the two alternators in a direction O C at right angles to A B. This current is proportional to A B and inversely proportional to the reactance in the circuit, including the synchronous reactance of the alternators. This current produces a torque proportional to

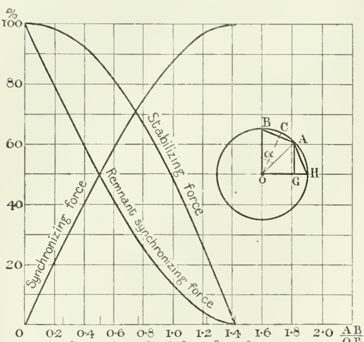

FIG. 12.

$BA \cos a/2 = OA \times 2 \times \cos a/2 \times \sin a/2 = OA \sin a$, which corresponds to O G in the diagram. This is the force tending to pull the two generators into exact synchronism, and will be called the synchronizing force. The force opposing a small alteration of the angle a would be proportional to $\delta \sin a = \cos a\, \delta a$. This is the force tending to prevent any angular displacement from any particular angular position of the voltages, and will be called the stabilizing force. Thus the synchronizing force between the two alternators is a maximum at 90°, being equal to O H in the diagram; but in this position a small alteration in the angle will cause no alteration in the force between the two alternators, so that they cannot be run in parallel with this phase difference between their voltages. In other words, the stabilizing force is zero. On the other hand, when $a = 0°$ the two generators are in exact synchronism and the synchronizing force is zero, while the stabilizing force is a maximum.

Assume that the alternators are running with a constant angle of a between their voltages, and that a torque proportional to O G is acting between them. If now an additional force proportional to G H is applied in such a direction as to retard the lagging or to accelerate the leading alternator, the angle between the two machines will be increased to 90° and they will drop out of step. $GH = 1 - \sin a$ is therefore a measure of the additional force required to pull the machines out of step when there is an angle a between their voltages. This force may be called the remnant synchronizing force, and is the difference between the synchronizing force at angle a and the maximum synchronizing force at angle 90°.

Thus there are three forces which must be considered:—

1. The synchronizing force, tending to pull the voltage into phase. This is proportional to the sin of the angle of displacement a.

2. The stabilizing force, tending to prevent any displacement from the angular position a. This is proportional to cos a.

3. The remnant synchronizing force, which is the difference between the maximum synchronizing force and that at the angle a, and is proportional to $1 - \sin a$. This force is therefore a measure of the ability of the generator to remain in synchronism when running under conditions corresponding to an angle a between their electromotive forces.

In order to show the relation existing between these three forces at all angles between zero and 90°, the curves shown in Fig. 3 have been plotted, showing $\cos a$, $1 - \sin a$, and $\sin a$, as functions of the ratio B A/O A, which is the vectorial difference of the voltage of the two alternators divided by their voltage. On the horizontal scale is also given the values of a for the different ratios.

In order to obtain a concrete idea of the values involved, it will be assumed that the two generators have each a synchronous reactance of 50 per cent. Then the maximum current that can circulate between them under a 90° displacement is 1·41 times the normal, *i.e.* A B = 141 per cent. Since the current is displaced 45° from the voltage of each generator, the torque $= 141 \times 0{\cdot}707 = 100$ per cent of normal, *i.e.* the maximum synchronizing force = 100 per cent of the full-load torque of one machine. If a reactance of 50 per cent is placed between the two generators, the maximum current that can flow under 90° displacement $= 141/150 = 0{\cdot}94 \times$ full-load current, and the torque $= 0{\cdot}94 \times 0{\cdot}707 = 66{\cdot}6$ per cent of the full-load torque. Thus at any angle the synchronizing force = 66 per cent of that which would exist were there no reactance between the generators.

Assume that 50 per cent reactance is to be placed between two generators that are to operate in parallel with 50 per cent of the normal load of one generator passing into the busbar section of the other generator. This transfer of load corresponds to a voltage across the reactance $= 0{\cdot}50 \times 0{\cdot}50 = 0{\cdot}25$ per cent of normal, or A B/O A = 0·25. In this case the angle $a = 14° 22'$. This reduces the remnant synchronizing force to 75·5 per cent of the maximum value given on the curve. Also the stabilizing force is reduced to 98 per cent of the maximum. These figures are taken from the curves (which are based upon the assumption that there is no external reactance in circuit). The introduction of the synchronous reactance would therefore reduce the above values to 66·6 per cent of those given on the curve. This is equivalent to a remnant synchronizing force of $75{\cdot}5 \times 66{\cdot}6 = 50{\cdot}3$ per cent, and a stabilizing

force of $98 \times 66 \cdot 6 = 65 \cdot 2$ per cent of the values that would exist with no external reactance in circuit. These values should in most cases be perfectly satisfactory. Where there is a group of generators in parallel on a busbar section which is separated by a reactance from another group, the synchronous reactance of the whole group must be considered in determining the value of the external reactance.

In the manner indicated above it will be possible to calculate the forces existing between any two alternators or groups of alternators provided the synchronous reactance, the size of the busbar reactance, and the transfer of energy from one generator or busbar section to another is known.

In the above example it is assumed that the generators are rated at unity power factor. If the rating is at 80 per cent power factor the forces in the above examples should be multiplied by 1·25. Also it must be noted carefully whether the busbar reactance is rated on unity or on a lower power factor.

It is obvious that the above method of treating the subject would have to be carried much further in order to cover all possible cases, but it is believed that it will serve to indicate in a general way the principal factors that are involved.

Among the papers which have been published recently on this general subject, and in the English language, the following may prove of interest :—

STEINMETZ, C. P. Development of the modern central station. *Transactions of the American Institute of Electrical Engineers*, vol. 30, p. 1213, 1911.

MERRIAM, E. B. Some recent tests of oil circuit breakers. *Transactions of the American Institute of Electrical Engineers*, vol. 30, p. 1195, 1911.

SCHUCHARDT, R. F., and SCHWEITZER, E. O. The use of power-limiting reactances with large turbo-alternators. *Transactions of the American Institute of Electrical Engineers*, vol. 30, p. 1143, 1911.

DURGIN, W. A., and WHITEHEAD, R. H. The transient reactions of alternators. *Proceedings of the American Institute of Electrical Engineers*, vol. 31, p. 897, 1912.

EBY, E. E. Recent designs of power-limiting reactances. *General Electric Review*, vol. 15, p. 788, 1912.

LINCOLN, P. M. Protection against short-circuits. *Electric Journal*, vol. 10, p. 1217, 1913.

HOLLIS, E. P. Reactance and reactance coils in power circuits. *Journal I.E.E.*, vol. 52, p. 254, 1914.

DISCUSSION BEFORE THE INSTITUTION, 26TH MARCH, 1914.

Mr. Woodhouse.

MR. W. B. WOODHOUSE : There is a natural tendency—I suppose based on past experience—to look with suspicion on all protective devices ; so many which were once in use have been discarded. In considering, therefore, any new apparatus I think the first criticism is : What is the necessity of these particular devices ? And the next is : What additional disadvantages do they introduce ? Reactance coils are introduced broadly for two reasons, which the authors have given. The protection of apparatus is the first ; the second is the limitation of disturbances caused by a breakdown on any particular part of a system. Practically all the apparatus that we use on alternating-current supply systems possess reactance as well as resistance, with one important exception, the switchgear ; and the question naturally arises whether we can take advantage of the reactance that is inherent to the apparatus that we use. The protection of a generator by an external reactance coil is unnecessary if that generator can be built to withstand being short-circuited ; and we all know that the progress of the last few years has been in the direction of constructing alternators and synchronous machinery generally which will withstand being short-circuited. We have been assisted in that by the introduction of automatic pressure regulators, and nowadays the 6 per cent reactance to which the authors refer on page 512 as an average figure for a generator, seems to me to be much too small. I should think that modern practice tends more to the use of 10, 15, or even 20 per cent reactance. If alternators are built with that reactance they can protect themselves : and therefore a reactance coil in a generator circuit is unnecessary for the protection of the generator. There is, of course, the momentary rush of current to consider when a generator is short-circuited, and we hope that it is not beyond the powers of the designers of generators to effect a reduction of that. The same holds true, I think, as regards static transformers. It is quite easy to build a static transformer with considerable reactance, and it is possible I think to build it to withstand being short-circuited. Feeder protection is the next important matter ; but this seems to me rather a question of the limitations of the switchgear that is used. It is a number of years since Mr. Andrews showed us how to protect feeders by introducing reactance ; a modern protective device, the split-conductor system, follows on those lines. So far then as the apparatus to be protected is concerned, we are left with only switchgear to consider. The disconnection of a faulty section by switching is equivalent to the gradual introduction of resistance into the circuit. In doing so the switch has to absorb a certain amount of energy—in some cases a very considerable amount of energy—and those of us who have knowledge of the destructive results of switch failures will realize that there is a very real need for some additional protection unless the design of switchgear can be improved by introducing reactance in the switchgear itself. The growth in the amount of energy absorbed by a switch follows a very definite law : it increases to a maximum and then decreases. That maximum is greater the greater the amount of reactance in the system. I do not propose to discuss the theory of the subject, or of the amount of power that has to be absorbed by a switch in opening a circuit ; it is quite a simple matter, depending amongst other things on the amount of reactance in the system as a whole. We thus have the curious condition that to protect our switchgear we add reactance, which in itself is destructive owing to the fact that energy is stored in it. For the protection of the switchgear, I think there is no doubt that reactance is not only advisable but essential. In considering the limitation of disturbances it seems to me that the proposal to introduce reactance coils in the generator and feeder

r. oodhouse.

circuits is scarcely necessary except under special conditions, since the diagrams and particulars in this paper show that it is preferable, as covering a much wider range of disturbances, to put those reactance coils in the busbars, *i.e.* to have sectional reactance coils. With a proper use of sectional reactance coils and a correct design of apparatus, both feeder and generator reactance coils seem unnecessary. It is left to the operating engineer to consider the cost of all this. We have first of all the cost of the reactance coils; and secondly there is the cost of using them. The latter, however, is very small compared with the cost of compensating for the reactance that we have introduced. The pressure regulation of the system is made worse by these devices. We must therefore compensate for that by synchronous machines and synchronous condensers, and we have to add the capital cost of those machines and the cost of running them, which is a fairly large sum. The authors have said, and I fully agree with them, that the whole question is one of insurance. The introduction of these coils is in the nature of paying an insurance premium. It is a question of what is the value of the risk. If the apparatus can be improved and the risk reduced it is possible to use smaller reactances; and obviously the smaller the reactance the simpler is the system and the less costly it is to operate. The authors' appendix on parallel running is interesting, and I should like to know what they think are the limits of reactance that may be introduced between machines whilst still retaining satisfactory running. I have for some time been running two generators in power stations about 13 miles apart with a natural sectional reactance in the overhead transmission line connecting the two stations; its reactance is of the order of 10 per cent; the reactance of each generator is about 20 per cent, and under these conditions there has been no difficulty at all in parallel running. It would, however, be interesting to know what is the limit—how much reactance can safely be introduced between the machines while still preserving satisfactory running conditions. The limits to which we can go, such as those that I have mentioned, are obviously made possible by the use of steam turbines, so that although we may have introduced disadvantages by using high-speed generators, we have obtained corresponding advantages owing to the prime-movers that drive those generators.

tridge.

Mr. G. W. PARTRIDGE: I am very much interested in the use of these reactance coils, and more especially in their use in the case of large turbo-generators. As far as I am aware the London Electric Supply Corporation was the first supply authority in this country to make practical experiments on reactance. These particular reactance coils, I may say, have now been in use for over three years, and have proved in every way of advantage in taking care of short-circuits. It became imperative that some sort of current-limiting device should be used in connection with our power supply to the Brighton Railway, which is a high-tension single-phase railway in which the electrical equipment on the trains is connected direct to the busbars; that is to say, there is no intermediate sub-station or transformer to act as a buffer in the case of a short-circuit. I have seen the large concrete-core reactance coils which are used in America, and, provided there is sufficient room in the generating station, they are very satisfactory. The coils used by my Company contain a certain amount of iron, and weigh when complete between 13 and 15 tons. They are designed to withstand momentary short-circuits amounting to 20,000 amperes. The advantage of this form of reactance coil appears to me to be that it takes up less room, it can be placed in any position without fear of any stray fields, and, lastly, as the authors have pointed out, it can be made exceedingly strong and able to withstand the stresses that are set up in it during short-circuits. I should like to ask the authors their opinion of the arrangement of reactance coils on busbars which is shown in Fig. A here- Mr. Partridge.

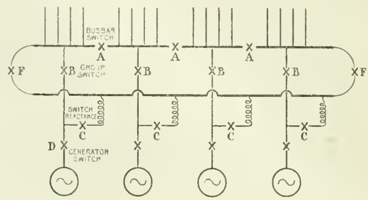

FIG. A.

with, and which is somewhat different from that illustrated in the paper. With this arrangement one can get great flexibility. On top load, for instance, with all four generators running, by opening the switches A and F each generator feeds its own group of circuits, or, if preferred, by opening group switches B and closing F the four generators could supply through the four reactance coils. At times of light load one generator could feed any particular group of circuits direct, and by opening the switch A on either side of the group could feed the rest of the circuits through the reactance, or could feed three groups direct, leaving the fourth group supplied through the reactance coil. The arrangement shown appears to have the following advantages:—(1) Circuits may be supplied at different pressures if required; (2) the danger of bad synchronizing is avoided; (3) short-circuits on sections of busbars or groups are protected against, the switch C opening and cutting off the faulty section; (4) the number and size of the reactance coils is reduced to a minimum.

A few weeks ago I made a large number of experiments on short-circuits, with and without reactance. Altogether 23 short-circuits were made, and by means of an oscillograph we were able to take observations of (1) the momentary short-circuit current with and without reactance coils; (2) the rise in pressure across the terminals of the oil switch when the circuit was opened, and the actual behaviour of the switch itself; (3) the effect on the field when the generator was short-circuited. These experiments were not entirely in connection with the behaviour of the reactance coils, but I should like to show a few of the oscillograph curves which were obtained on this particular occasion, the records being taken by our President, Mr. Duddell. The tests were made on a 7,500-kw. turbo-generator. These generators have a very high internal reactance, being specially built for the rather severe service of the single-phase railway, in which, as I

have previously pointed out, the trains are fed direct from the busbars. Fig. B shows the result of a short-circuit with the reactance coil in series. It will be noticed that the switch breaks the circuit in about $\frac{1}{8}$ second. The current was between 4 and 5 times the full-load current of the generator, that is to say, between 3,500 and 4,000

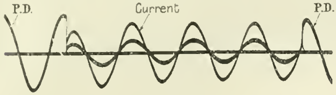

FIG. B.

amperes. The amount of the short-circuit current varied considerably, depending on the particular point on the wave-form at which the short-circuit occurred. Fig. C shows the effect of breaking a short-circuit without the reactance coil in circuit. The effect of this short-circuit was to make the switch arc badly. This arcing of oil switches, which is clearly shown on the oscillograph, is a very serious fault. A great many switches have been blown out and destroyed owing to their not being

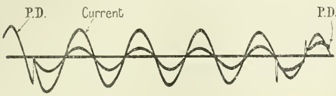

FIG. C.

strong enough to resist the explosion that takes place during the arcing. In other cases the busbars and the terminals have been damaged by the conducting gases escaping and short-circuiting the bare conductors. I always make it a rule now that all bare conductors near oil switches are to be covered up. Last, but not least, there are the very serious rises of pressure and surges that are set up by the arcing in these oil switches. The use of reactance either inside the switch or externally will tend to get over this difficulty of arcing. Fig. D is a record from an oscillograph which

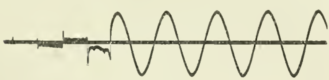

FIG. D.

was connected across the terminals of the oil switch to see what rise of pressure took place; it will be seen that the oil switch arced badly, and from my notes of the test I see that the oil was again thrown out of the oil tank. There was no pressure rise across the terminals of the oil switch. Fig. E shows the effect of a short-circuit on the exciting current of a generator. There was no reactance in series on this particular occasion. It will be noticed that there was alternating current in the field before the short-circuit occurred. As soon as the short-circuit came on, the exciting voltage was reversed, and the field current was increased to about $2\frac{1}{2}$ times the mean exciting current. It will be noticed that the alternating current has twice the periodicity of the main current. I suggest that it would be a good thing if a reactance coil were placed in the field circuit so as to choke back this alternating current. It certainly would have no effect on the continuous current, and I expect it would tend to reduce the short-circuit current of the main generator itself. As soon as the short-circuit was cleared, it will be seen that the field current gradually fell and became normal, the pressure also becoming normal afterwards. In the other two experiments, of which I have not shown the curves, we were able, by means of reactance coils, to short-circuit the

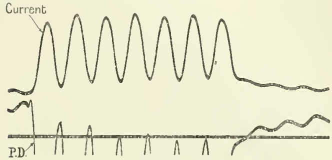

FIG. E.

generators, not opening the switch at all, but allowing the short-circuit to rise and gradually die away as the machine became demagnetized. The last experiment was the effect on the third phase of a three-phase generator when two phases were short-circuited. We disconnected the third phase from the neutral point and connected the oscillograph across it. On short-circuiting the other two phases we found, much to my surprise, that we had no rise of pressure in the idle phase, the phase itself being only slightly distorted.

Mr. J. SHEPHERD: I think that anybody who has had charge of a large alternating-current power station sooner or later comes to the conclusion that reactance is necessary in some form or other. At the same time we must not forget that two years ago reactance coils were practically unknown; but now (in Fig. 10) the authors have introduced them on a large scale. I have made an approximate estimate of the cost of such an arrangement of reactance coils, and I find that it is something like 10 per cent of the cost of the generating plant. If to that is added the cost of the connections, blowers, air filters (that is if they are air blast, or water coolers if they are of the oil type), probably the cost would be something like 12 to 15 per cent of that of the generating plant. I have some doubt as to whether a case has yet been made out for such a wholesale provision of reactance. I should like the authors to give us some idea of the size of the system or station for which the provision of reactance coils to this large extent is really justified. I notice with some surprise that while the authors refer very largely to reactance, which is only one form of protection, nothing is said about relays, which are another form of protection. I think that the provision of a suitable relay is probably a more sensible method of protecting the feeders than by inserting reactance coils in them, because, after all, a short-circuit on a feeder is rarely of an instantaneous nature, and it generally takes some little time to develop, that time being sufficient for a good system of relays to isolate the feeder. I think, however, in the case of generators there is need to introduce reactance, espe-

Mr. Shepherd. cially in the older machines that were designed with the view of good regulation, and therefore of low reactance. For instance, a machine purchased about four or five years ago probably had a reactance of something like 3 or 4 per cent, whereas a modern machine would certainly be built with a reactance of 6 or 7 per cent; and if it had to work in a large station under rather adverse conditions the designers would probably introduce something like 10, 15, or even 20 per cent of reactance inside the machine. Reactance must of course be inserted in the machine circuit, whether introduced into the machine itself or in the form of an air coil or transformer shell without the internal iron. Then, again, if the busbar system is fairly extensive there are always risks of short-circuits. The simplest place in which to install reactance coils seems to be wherever the busbar is cut into sections. The provision of reactance coils becomes very expensive. If the air path or concrete type is used the coils cannot be placed in any ordinary building without a risk, I will not say of melting the steelwork, but certainly of making it very hot. If they are of the iron type they become very heavy, and it is very difficult to find room for them, especially in some of the older power stations, where it might be necessary to construct a special building to house them. There is another form of protection which is not mentioned in the paper and on which I should like to hear the author's opinion, namely, what has become of the large induction generators that were so highly spoken of by Dr. Steinmetz about four years ago when they were introduced into the 59th-street station in New York? Those generators seem admirably suited for running in parallel with synchronous machines, as they give no current when short-circuited.

Mr. Hollis. Mr. E. P. Hollis: I think it is quite time that we in this country studied the uses to which reactance can be put in large power schemes. The present paper does not by any means exhaust the uses for reactance coils. There are many other uses, such as for constant-potential transmission and pressure-limiting on extremely long lines. The paper concentrates attention on one particular phase of the question, namely, the protection of the power station. One of the first effects of reactance coils is to remove from the system all danger of complete disablement, and it will be appreciated that the engineer having charge of the operation of a reactance-protected system has a large load removed from his mind. No longer is a system dependent on the idiosyncrasies of an overload relay for its safety, or on the reliability of a current transformer. The advent of reactance coils involves many changes. For instance, it is no longer essential to earth the star point of only one generator. The high reactance offered to triple-frequency currents is sufficient to damp down most third harmonic currents to a negligible value. Again, heavy expenditure on quickly operating switchgear is unnecessary, and the rating of existing switchgear can be increased. It has been feared that the advent of reactance in generators would seriously impair the regulation of the system, but it is necessary to look at the matter from the point of view that since the voltage regulator is now available the worst regulating generator can be made to give a fairly constant pressure, and I know of a number of installations in which generators have been purposely given large reactance in the full knowledge that a voltage regulator was to be used. Objections have been raised to the use of reactance coils in long feeders, because Mr. Hollis. it is said that they make worse an already bad regulation. But reactances can be used advantageously in these cases with the effect of improving the regulation if one provides synchronous plant at the receiving end. Such reactance coils also act as current limiters. By varying the amount of leading current drawn from the line it is possible by utilizing the phenomenon of the rise in voltage due to the leading current flowing through the reactance, to run the feeder at a constant potential, irrespective of load. Against this it is said that the cost of the synchronous plant would be prohibitive. That is not true in many cases. The provision of the reactance of the synchronous plant improves the rating of the line, as well as its efficiency, and it does not require a very long line in order to make the installation of such plant profitable. This is quite apart from the advantages gained by constant potential at the receiving end. There are very many lines in this country which are working at below 75 per cent of the output at which it would be possible to work them were a constant-potential system adopted; and transmission lines are very costly. For the protection of generators I find that many engineers while accepting the benefits of reactance prefer to use it internally only, and do not see any substantial reason for the use of external reactance coils. Internal reactance, however, does not protect a generator from the great influx of power which occurs when that particular generator breaks down, or against a concentration of potential across the end turns due to high-frequency surges. An external reactance would save the machine windings from that total destruction which would be possible were the reactance internal to the machine. I want to join issue with the authors when on page 512 they assert that "Where a step-up transformer is connected between a generator and busbars, it may be designed with high internal reactance, thus giving the effect of a reactance coil without any appreciable additional cost." That is a view, I know, which is largely held. But no amount of internal reactance in a transformer protects the generator against that likely contingency of the transformer itself breaking down. It may be argued that the same can be said if the reactance coil itself broke down. That, of course, is quite true, but there is no comparison between the factor of safety of an air-core reactance coil and that of a transformer where one has high-pressure conductors in close proximity to metal-work, and where the precautions against breakdown cannot be nearly as effective as in a separate reactance coil. Again, it does not by any means follow that reactance internal to the transformer will protect the generator on a short-circuit at the most favourable position, namely, on that side of the system remote from the generator. High reactance is attained in many transformers by the use of magnetic shunts, and it is well known where reactance is obtained by the use of an iron circuit that such reactance is useless in the face of a heavy short-circuit current, owing to the great reduction of the permeability of the iron path.

Reference has been made to the value of reactance coils in the event of a misphase in the synchronizing of generators, and the "doubling effect" has also been mentioned. There may also be a quadrupling effect in the matter of pressure, for on many oscillograms the pressure wave does not oscillate about the

zero axis, but entirely above it, so that the pressure between the windings and earth may be four times the normal. There is a fashion nowadays to use self-synchronizing machines, motors, and rotary converters. I believe in self-synchronizing generators, the synchronizing current being limited by reactance coils. This is a very old method of synchronizing, for I am told that on the earlier Ferranti boards synchronizing coils were provided. I believe, however, that the system has not come into general application owing to the fact that it was not an easy matter to design an adjustable reactance. A reactance of fixed amount had to be made Mr. Hollis. so high that it would limit to a reasonable value the flow of current on switching in, and also so low that it would permit the generators to run in phase when they had settled down to normal running. The compromise

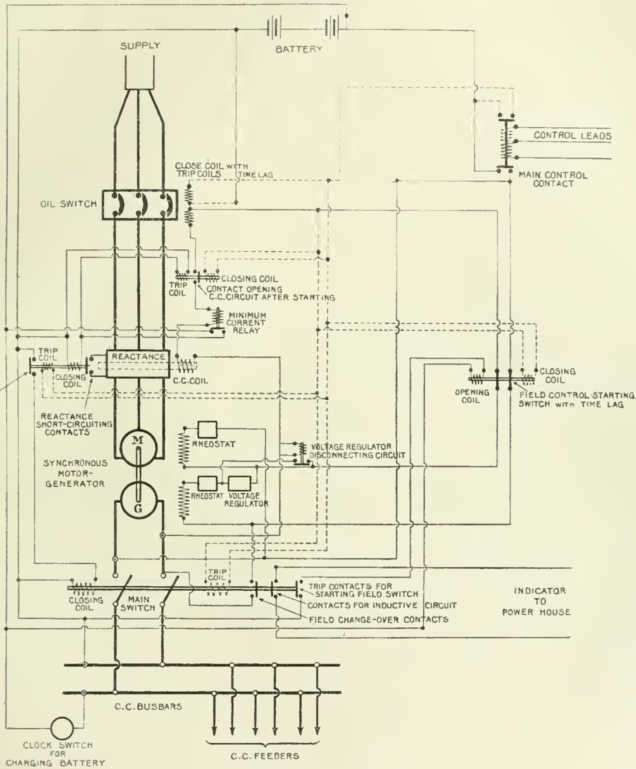

FIG. F.—Starting Connections of an Automatic Sub-station with Adjustable Reactance Coils.

could not be very effective. If a reactance of adjustable value were employed, I think that generators could be synchronized in this fashion with great ease. I have proposed * to make iron-core reactance coils adjustable

* E. P. Hollis. Reactance and reactance coils in power circuits. *Journal I.E.E.*, vol. 52, p. 254, 1914.

Mr. Holli- by turning to account the phenomenon that if the core of the coil be fitted with a winding through which continuous current is passed, the iron is given a magnetic bias, with the result that the reactance is increased. The value of the reactance is then dependent upon the strength of the continuous current, and by varying this current the value of the reactance can be adjusted. A generator can therefore be synchronized quite easily without any shock, the reactance being gradually reduced until the machines fall into step. Indeed the generator might be run up as a motor in case of emergency, the synchronizing time being used for warming the engine instead of allowing the usual warming period to elapse before starting up.

One of the developments of the future will be the automatic sub-station. I cannot here attempt to make out a case for such sub-stations, but I merely wish to show how adjustable reactance coils can contribute to their design. There are a number of sub-stations at present in operation abroad in which rotary converters are started up by varying the alternating voltage at the end of the feeder by means of an induction regulator, so bringing the converter up to speed, and relays effect the necessary connections on the continuous-current side; but if the feeder is part of a large system and does not radiate straight from the station, such a method of starting is impossible. Fig. F illustrates without elaboration the principle on which the starting connections of an automatic sub-station would be laid out. The sub-station is controlled through a 3-core pilot cable by the system engineer, or the "load dispatcher" as he is called in America. The operation of a 2-way switch under his control starts up or shuts down the high-tension synchronous motor-generator in the sub-station. Immediately the control switch is closed a solenoid completes the two circuits, one exciting the motor and generator from a battery, and the second energizing the continuous-current coil on the reactance core. In addition, this second circuit contains the oil-switch closing coil, a minimum current relay for short-circuiting the reactance when the machine has fallen into step, and a coil which disconnects the voltage regulator during starting, while the current is also made to pass through the generator armature. On switching on, therefore, the oil switch closes and starts the motor-generator, the reactance then being at a high value. As the generator speeds up, its voltage increases and opposes the battery voltage, in consequence of which the continuous current flowing through its armature is gradually reduced and the reactance of the coil diminished. Thus the motor-generator automatically runs itself up to speed. There comes a time when the motor locks itself into step with the supply and the continuous current flowing through the auxiliary coil on the choking coil has fallen to a low value. The minimum-current relay then trips and short-circuits the reactance. This "reactance short-circuiting" switch carries contacts which cause the main switch on the continuous-current side to close. Prior to this with the current through the auxiliary coil falling to zero the voltage regulator is put into circuit, and on the short-circuiting of the reactance raises the generator voltage to the necessary value. On closing, the main switch completes the contacts which change over the field from separate to self-excitation, and the machine then runs under the same conditions in a similar way to other machines installed in automatic sub-stations. Time lags are put on most of the Mr. Ho switches in order to give the several relays time to act. When the system engineer reverses the position of his control switch a tripping circuit is energized which opens the switches and sets them for starting up. Arrangements are also made for charging the battery at periodic intervals by means of a clock switch; and in order to facilitate this it is arranged that the battery has a smaller voltage than the generator.

In conclusion, it has been represented to me on several occasions that there is no great necessity for us to apply ourselves to the investigation of these very heavy power problems, and particularly of the use of reactance coils on long transmission lines, on the ground that we have in this country no large power schemes or long transmission lines which require such coils. I do not accept that as true, but even if it were, from the Imperial point of view it is material that we should investigate this question, since in our Colonies and Dominions large power schemes and long transmission lines will shortly have to be installed.

Mr. E. B. Wedmore: I should like to draw a broad Mr. Wedm distinction between reactance coils used in series in the system and those employed for paralleling parts of the system. If the reactance coil is in series, the whole of the load current must pass through it, and it introduces all the objectionable features of additional reactance in the circuit. Paralleling reactance coils, however, carry only a small portion of the load current at any time, and thus have relatively little influence on the power factor of the system. Other things being equal, one would therefore prefer the use of paralleling reactance coils to series reactance coils. Fig. 10 shows the use of the different kinds of reactance coils that have been discussed, and I should like to follow in this figure the function of the several different kinds. It is generally agreed that reactance in the generator circuits, whether external or internal, is necessary for the protection of the machines themselves. It is not commercially practicable in the present state of the art to protect the switchgear in a station containing 100,000 kw. of plant by the insertion of reactance coils at this point. There are several stations now in contemplation of a capacity of about 100,000 kw., so that the problem presented by such a case is one of immediate, considerable practicable importance. The diagram illustrates such an installation. In order therefore to protect the numerous switches shown in this diagram connected directly to the busbars, it is necessary to employ some further means, and we choose by preference paralleling rather than series reactance coils. The busbar section reactance coils by cutting up the system into sections and limiting the transfer of current have a limiting effect on the short-circuit current on every switch shown in the diagram. Generator or feeder reactance coils have a similar effect, but do not protect the switches in the case of a fault on the busbar side of the reactances. It might be thought that by careful design one might eliminate the risk of such an accident occurring, but one has to remember the innumerable sources of accident which lie outside the control of the designer, and which exist even in the best-regulated stations. Having regard to the supremely important position in the system occupied by the main station busbars, it is essential that one

should provide means to ensure that the switches connected thereto will not be strained beyond their limit of rupturing capacity. This is the first function of the busbar reactance coils. The second function is to limit the short-circuit current, which can flow out of the station into a section of the distributing switchgear. The use of feeder reactance coils for these purposes has the disadvantages associated with series reactance coils. I take it that there will be very few stations in the immediate future having an output of 100,000 kw. in which we shall not find step-up transformers employed to raise the voltage to, say, 20,000 or 30,000 volts. These transformers are likely to be installed in the feeder circuits, and their inherent reactance will assist in limiting the short-circuit current outside the station itself. The size and therefore the cost of busbar section reactance coils depends upon two features, namely, their ohmic value and their current-carrying capacity. The ohmic value of the reactance is that feature which limits the current transferred from section to section on a short-circuit, and is the feature which we rely on to give protection. The current-carrying capacity determines the amount of load current which can be transferred through the reactance coil. The protection provided by sectionalizing the busbars may be increased in two ways, that is, either by decreasing the size of the section, or by increasing the ohmic value of the reactance. I see that the authors suggest reactance coils with an ohmic value giving a 50 per cent pressure-drop on the rated output of one section. This figure appears to me altogether too high. Supposing that no reactance is used, the short-circuit current in the case illustrated will be 50 times the output of the section. If an infinite reactance is provided, the short-circuit current will be 10 times the rated output of a section. The proposed 50 per cent reactance reduces the short-circuit current to approximately 13 times the output of the section, which nearly approaches the result obtained with an infinite reactance. The first 5 per cent reactance inserted is very much more effective than the last 5 per cent. The addition of, say, 5 per cent reactance will have hardly any effect on the limiting value, whilst it will affect the cost by plus or minus 10 per cent. This indicates that the provision of reactance has been overdone. I find that an ohmic value of 20 or 25 per cent gives a more satisfactory commercial solution in the above case. If 50 per cent is necessary with sections of the size proposed, one should consider whether it is not better to obtain protection by reducing the size of the sections themselves.

There is a second objection to the use of so high an ohmic value, and it is this: In order to operate the plant without excessive differences of voltage between the sections, one cannot transfer from section to section through the reactance coils both heavy energy and magnetizing currents. Say one machine has been shut down and current is being transferred from adjoining sections to help out the remaining machine, this machine must now furnish practically the whole of the magnetizing current where 50 per cent reactance coils are employed, and this seriously limits the output of the machine. In determining the current-carrying capacity of the reactance coil, one should avoid introducing the necessity for constant operation of busbar switches. If the current-carrying capacity is too small it will not be practicable to shut down the machines without resorting to the operation of the busbar section switches. If there are two machines per section, and if the reactance coils have an ohmic value of about 20 per cent, and a current-carrying capacity of about 30 per cent of the output of the section, this will be found to give a very good compromise between excessive cost and excessive switching operations. Referring, again, to the second function of busbar section reactance coils, namely, that of protecting the distribution switchgear, this function is one of the first importance in the present stage of the switchgear market. The switchgear shown in Fig. 10 already represents a heavy expenditure, but the number of these switches is but a small fraction of the total number of switches that will be required in the distributing plant. There may be many hundreds of consumers in the area fed by this plant, each of whom will have one or more switches on his premises, and one cannot furnish switches for this purpose capable of dealing with "dead" short-circuits on 100,000 kw. of generating plant, or even 40,000 or 20,000 kw. of plant. It is therefore of the first importance that the size of the sections should be kept down to as low a figure as possible having regard to the size of the generating units which must be employed. Even with this protection some further safeguard is necessary at the present time.

Mr. Wedmore.

We have in the Newcastle district an example of a plant system of the magnitude under discussion. A large number of transformers are employed in the system; the reactance of these transformers and of the cables carrying the current over this wide area has a very beneficial effect in keeping down the short-circuit current on individual switches, yet one knows that difficulties have been experienced with switches in the neighbourhood of the generating stations. The first safeguard is obtained by isolating the sections of the distributing system fed from different sections of the busbar; but this alone is not sufficient. A mile of 0·1 sq. in. cable has a very useful effect in reducing the short-circuit current on the individual consumer's premises, if that feeder is not in parallel with numerous other feeders. It is necessary at present to utilize this feature for the protection of the distribution switchgear. This is done by subdividing the trunk cables leaving a section of the main station into branches of smaller section, leading to small distribution boards. This arrangement has also the advantage that the individual consumer's switch is supported by several switches in series before the generating station is reached, so that in the rare event of failure of one of the smaller switches, the disturbance is limited by one of the larger switches supporting it, so that only a small area in the distributing system is affected. There is an alternative method of limiting a short-circuit on the individual feeder leaving the main station, in which reactance is employed in such a way as to combine the advantages of the series and paralleling types. I refer to the arrangement described in Hilliard's Patent No. 8571/1905, in which he shows the use of two switches in series so arranged that when a fault occurs one switch cuts in reactance and the other then operates to open the circuit.

I wish to emphasize the point raised by Mr. Everest on the design of busbar reactance coils. Such a coil is really a very long extension of the main busbar and requires to be treated with very great respect. I do not

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Mr. Wedmore. like the idea of unnecessarily bringing a large mass of heavily earthed ironwork into close proximity with the main busbars.

Mr. Allingham. Mr. G. C. ALLINGHAM: Reference has been made to the fact that by providing the generators with high internal reactance they are protected against large increases of current. There is also the question of protecting them against pressure rises. Such pressure rises tend to break down the end turns of generators or transformers, and by putting an external reactance in series with it the end turns of a generator or transformer are in effect removed to the reactance, thereby reducing the risk of breaking down the end turns in the case of a surge of potential.

Mr. Everest. Mr. A. R. EVEREST: The authors have given in this paper a very good review of the factors entering into the selection of current-limiting reactances, but there appears room for some discussion regarding the relative value of reactance in the different locations. It may be stated as a fundamental proposition that the generator windings must always be protected. A generator of good modern construction should readily withstand the shock of 10 times full-load current; 50-cycle machines can be designed without difficulty to contain internally the limiting reactance necessary to keep the short-circuit current within this value. With 25-cycle generators this cannot always be done and it is sometimes necessary to provide additional reactance externally to the generator; when such additional reactance is used it should always be placed so as to form a continuation of the generator windings. This, while taking care of the generator, leaves several other points requiring protection, as pointed out by the authors. We wish to keep within reasonable limits the duty thrown upon feeder and distribution switches in the event of a fault occurring beyond them. It is very undesirable that the entire busbar system shall lose its voltage in the case of a fault. In the event of a fault on one generator it is desirable that the current which can be fed into it from the other generators shall be limited, otherwise the generator switch becomes severely tasked. In considering the relative advantages of reactance coils placed between the sections of the busbars as compared with feeder reactances, we find that feeder reactances protect the feeder and distribution switches, but do not protect the generator switch, nor do they limit the lost voltage to any one section of the system. They produce an objectionable regulation drop in the feeder voltage, and the space and cost involved become very serious if a large number of such devices are contemplated. On the other hand, reactance coils placed between the busbar sections give protection to both feeder switches and generator switches, and limit to the busbar section immediately affected the loss of voltage in the case of a fault. The objectionable effect upon regulation is not present, since normally they are carrying little or none of the load current. As regards the different types of construction available, the iron-clad type is probably best applied when it is necessary to place additional reactance close to the generator, since the space required for the air-core type is usually difficult to spare at this point. It must be admitted that the air-core type should have inherently a higher factor of safety against earthing than is provided by the best insulation on coils of the iron-clad type, and on this account the air-core type appears preferable for Mr. Ev reactance coils placed in the busbar sections.

Mr. Fay Hansen Mr. K. M. FAYE-HANSEN (*in reply*): I quite agree with Mr. Woodhouse that it is very important not to use protective devices without also considering the risks and the cost of installing them, and throughout the paper we have pointed out the disadvantages which are unavoidable if reactance coils are installed. With regard to the protection of the generator by means of generator reactances, this will probably not be so necessary in the case of new generators, because it is now fully realized that reactance in the generators themselves is very useful, and that it is possible and necessary to brace the windings of the alternators so strongly that they will not be distorted. It must be remembered, however, that the reactance here in question is not the synchronous reactance but the armature reactance. The synchronous reactance of modern generators is perhaps in the neighbourhood of 50 per cent, and often very much higher than that. For large 2-pole, and especially for 25-period generators, however, it is difficult to obtain more than 6 or 10 per cent reactance in the armature of the generator itself, and under these circumstances it may be justifiable in some cases to install external generator reactance coils; but I think these will be used mainly in connection with rather older generators that have been designed so that they cannot withstand short-circuits.

I quite agree with Mr. Woodhouse that it is correct to introduce reactance in step-up transformers for the protection of generators when such transformers are used. It is always possible to put sufficient reactance into transformers to limit the short-circuit current to a reasonable value, without using magnetic shunts. With regard to the breakdown of the transformer itself, the only danger of the generator being damaged is if the breakdown is between the terminals of the transformers. We know from experience that breakdowns in transformers are practically always between the various turns, and the current flowing into the transformers before the protective devices can operate will not in this case be of sufficient amount to endanger the generator.

With regard to the cost of operating these reactances, I do not think it will be appreciable, and it will not be necessary to use any synchronous machines to compensate for busbar reactance. In connection with feeder reactances, if due to other reasons there are no rotary converters or synchronous machines running, the feeder reactance would have to be so small that the regulation would not be affected to any extent. We certainly would not advocate installing reactance to such an extent that synchronous machines would have to be installed merely for the purpose of overcoming it. With regard to the question of the limits of synchronous reactance between the busbar sections, while still retaining satisfactory parallel running, it is impossible to give any definite figures because it depends so much on the conditions, such as the governing gear, sudden loads, etc. We think, however, that the figure for reactance given in the paper is rather the upper limit of what ought to be installed. We do not think it would be advisable to make it higher from the point of view of parallel running. With regard to parallel running, it has also to be considered that the reactance and the displacement of the voltages will influence the periodicity of the natural oscillations of the alternators, and in that way

Mr. Faye-Hansen.

may cause hunting. In deciding what reactance is to be installed, the hunting question has also to be considered.

We certainly think Mr. Partridge's scheme for installing reactance is a very good one. Generally speaking, it is somewhat like that shown in Fig. 10, because the arrangement amounts to putting reactances in the busbars between each generator and making arrangements so that those reactances can be short-circuited if desired. The method of arranging the switches seems, however, to have advantages compared with the straightforward system described in the paper. It was very interesting to see the oscillograms of the short-circuit tests.

Mr. Shepherd referred to the high cost of installing all sorts of reactances as shown in Fig. 10. In Fig. 10 we have installed reactances in all possible places for the purpose of showing where they eventually should be installed, and what influence they have if installed; but, as pointed out in the paper, we do not really recommend that as a rule all sorts of reactance should be installed at the same time, especially not generator reactances if the generators are designed so that they can withstand short-circuits. It should be pointed out, however, that where there are both generator and feeder reactances, each may be smaller than where only one is used. As previously pointed out, it is rather difficult to design alternators of a 2-pole type with such a high reactance as 15 or 20 per cent without raising the cost of the alternator considerably. In these cases the limit at present seems to be more in the neighbourhood of 10 per cent.

Regarding the use of relays as a protection instead of reactance coils for preventing damage due to short-circuits, I do not think that any relay and commercial switch can be made to cut out the fault before full short-circuit current is reached, if the short-circuit is due to mechanical damage, misphase, or similar cause.

Induction generators are practically obsolete, due to the fact that they cannot supply any magnetizing current themselves, and it is therefore necessary that all the other alternators should be very considerably larger in order that they may supply the magnetizing current, and on account of their larger size they supply more current in case of a short-circuit.

I do not agree with Mr. Everest and Mr. Wedmore that air reactance coils are necessarily safer than reactance coils designed with iron cores. I think it is generally recognized that apparatus which are placed in oil and have the advantage of oil cooling and oil insulation are safer than apparatus that are air cooled; and I think that advantage is important enough to outweigh the disadvantage of having metal in the neighbourhood of the busbars. It is, of course, possible to insulate the complete iron-clad reactance to earth (including the iron) as is done in case of the air choke coil, using large porcelain insulators.

Mr. Faye-Hansen.

Mr. Hollis has dealt with reactances for a number of different purposes. The question of current-limiting reactances for the purpose of protection is such a large one that if treated in a reasonable way it gives quite sufficient subject-matter for one paper. To deal with all kinds and uses of reactances is much too large a subject for one paper. I have already pointed out that I am of opinion that the internal reactance in a step-up transformer is a good safeguard for the generator, and in such circumstances it would have to be obtained without reactance iron, or with such a section of reactance iron that saturation would not occur.

I am glad to know that Mr. Wedmore agrees with us that busbar reactance is as a rule the most important and gives the most advantages. Mr. Wedmore states that a busbar reactance giving a 50 per cent pressure-drop with the rated output of one section is altogether too large. I agree that it is about the highest advisable limit, but this depends largely on the size of the busbar sections and the amount of energy which it is intended to pass through the reactance coil. It is true that the first 5 per cent of reactance inserted is much more effective than the last 5 per cent in a 50 per cent reactance coil, but the expense of the last 5 per cent is very much less than that of the first 5 per cent, especially if an iron choke coil is used. The main reason for advocating as large a reactance as possible between the busbar sections is to keep up the voltage on the sections adjacent to a fault, especially if the switches should not clear the fault, before the armature reaction of the alternator has time to play an important part in the voltage drop.

As to Mr. Allingham's remarks, of course it is quite true that the reactance coils also serve the purpose of protecting the end turns of generators against voltage surges. In the case of very large generators, however, this will not, as a rule, be of very great importance, because there will very often be one conductor per slot, and under those circumstances there is practically no danger of breakdown between one turn and another.

DISCUSSION ON "MOTOR AND CONTROL EQUIPMENTS FOR ELECTRIC LOCOMOTIVES." *

Birmingham Local Section, 25th February, 1914.

Mr. Carter. Mr. F. W. Carter: There is little in this paper to which I can take exception. At the bottom of page 388 the author says that the number of steps in the control system is dependent on the characteristics of the motor, and especially mentions that the lower the internal resistance the greater will be the number of steps. This is followed by a comparison between a 550-h.p. motor and a 100-h.p. motor, and it seems to be implied that the former motor has the greater number of steps because of its lower internal resistance. I do not think, however, that it is the resistance only that enters into the question, but rather the pressure-drop due to resistance, which may be no lower in the large motor than in the small motor, and in fact in some cases may be higher. I do not therefore think that as between one large motor and a number of small motors of the same type there need be any appreciable difference in the number of control steps. However, I agree with the author that the slope of the speed-torque curve affects the number of steps required; but the effect is only appreciable when motors of different types are compared, such as single-phase and continuous-current motors. The real consideration that determines the number of control steps is indicated by Mr. Lydall, and is this: The locomotive must be capable of starting as great a load as possible on the heaviest grade, which determines the minimum tractive effort, whilst the maximum is limited by the adhesion of the driving wheels. In order to get as much as possible out of the locomotive, it is necessary to bring the maximum and minimum tractive efforts as near together as is practicable, and a large number of steps are therefore used in the control; thus, the Butte, Anaconda and Pacific locomotives have 17 steps (10 series and 7 parallel). The Detroit-River Tunnel locomotives have 24 steps (9 with all motors in series, 8 with 2 in series and 2 in parallel, and 7 with all in parallel). Motor cars frequently have only 9 steps (5 series and 4 parallel), for the above considerations do not apply to these, and the limiting feature is simply the amount of jerking that the passengers will put up with when the train starts. On page 389 the author states that the self-induction of the winding does not affect the problem of starting, but he implies that in the case of tramway cars there would be some effect on account of the short time required for starting. I have seen a large number of records from automatic instruments of the amount of current taken by a train, and I have always found the rise of current (when each step of resistance is cut out) to be practically instantaneous: I conclude from this that the effect of self-induction is inappreciable in any case. On page 391 of the paper reference is made to the bridge method of transition from series to parallel. The fact that the accelerating current of a locomotive is varied according to circumstances of load, grade, and condition of rails, makes this method of transition less valuable than in the case of motor cars, where the same accelerating current can be maintained automatically under all conditions; for Mr. Carter. unless the transition is taken at the current for which the resistances are designed, a shock will be felt at the transition points very similar in nature to that felt when less perfect systems are used. In other words, for locomotive work the bridge system is not as valuable as in motor-car work. On page 396 the author mentions that where a high-voltage continuous-current supply is taken from an overhead line it is not advisable to break the current violently by means of a strong magnetic blow-out, otherwise surges may be set up in the line. I must say that I have never heard of this before, and believe that the 2,400-volt locomotives used on the Butte, Anaconda and Pacific Railway have contactors and circuit-breaking switches fitted with magnetic blow-outs. The author also says that there is very little automatic control apparatus used in this country. I think he might say that there is not very much used on locomotives at all, and the reason is that the locomotive is sometimes required to give all the tractive effort of which it is capable, whilst at other times it is worked with a lower tractive effort. Resistances could hardly be adjusted to give even peaks under both conditions, and it is felt that in the case of such locomotives the control is best left in the hands of the driver.

Mr. Poultney. Mr. E. C. Poultney: As a mechanical engineer most of my remarks must be in the nature of questions, which I hope the author will answer. In the first place I should like to know whether any system of air filtering is used in the case of electric locomotives fitted with fans to cool the motors, as I suppose that dust must be drawn in, and if blown into the machines would be detrimental to their working. I should also like to ask in connection with these large electric locomotives—some of which are of 2,000 h.p.—what is their weight per horse-power, approximate cost per ton, and operating cost per mile (that is to say, maintenance and running costs). A feature of the electric locomotives shown is the large power developed compared with steam locomotives, and it would be difficult to design steam locomotives of such high powers as, say, 2,000 or 2,500 h.p. Steam locomotives working with superheated steam develop about 11·9 i.h.p. per ton of total weight at speeds of from 55 to 60 miles per hour, or about 220 r.p.m. It will therefore be seen that a steam locomotive fitted with a superheater designed to develop continuously 2,500 i.h.p. would weigh with tender about 200 tons; and as 1·6 sq. ft. of heating surface (including superheater) are required per i.h.p. at 60 miles per hour, this boiler would have to contain at least 4,000 sq. ft. of heating surface. Looking into this question of cost, I find that £55 per ton is the figure given for a modern express locomotive, and that the operating costs for maintenance are from 2·6d. to 5·7d. per mile, that the running costs vary from 7·8d. to 10·1d. per mile, and that the total costs (*i.e.* maintenance and running), vary from 11·3d. to 15·2d. per train-mile. In conclusion I should like to show a slide illustrating

* Paper by Mr. F. Lydall (see p. 384).

the latest design of six-coupled bogie superheated locomotive designed for service on the London and North-Western Railway. The engine can maintain 1,400 i.h.p. at about 60 miles per hour, and weighs with tender 117 tons. Another slide which I have shows particulars of the draw-bar pull and indicated horse-power of an engine of this type when working heavy trains between Euston and Carlisle; and a third slide shows how steam locomotives have increased in size during the last 20 years. The small engine shown can develop about 500 i.h.p. and is superimposed on a large six-coupled bogie engine capable of developing continuously about 1,200 i.h.p.

Dr. C. C. Garrard: The author mentions four alternative electric-traction systems. I should like to refer to a fifth, viz. the series system. Some years ago a paper was read before this Institution by, I believe, Mr. Swinburne, in which this system of electric traction was discussed. The series system has come much to the front recently in connection with transmission schemes and also in industrial work; and I should like to know whether there is any possibility of its being applied to electric traction. I am rather surprised that automatic control has not been used on electric locomotives. The author mentions in connection with non-automatic systems the necessity of the driver watching the ammeter. In view of the recent discussions on the subject of railway work generally, it would appear that automatic acceleration would be very desirable in that it would leave the driver more time to watch the signals, etc. It is interesting to learn that cast-iron grids are satisfactory for the resistances on locomotives. There has been some prejudice against the use of cast-iron grids on account of breakage. Certainly in transit, unless special precautions are taken, such grids get broken. I note that cast-iron resistance grids can be used on the locomotives, whereas they get damaged if placed in a goods wagon. In my opinion it is the rough handling that such consignments receive at the hands of the staff which accounts for the breakage in transit. When they are once installed no further trouble results. I should have thought that liquid controllers could have been used on locomotive work with success. For electric winding machinery, for example, liquid controllers are universal. It seems to me that this is a more difficult problem than the starting and stopping of the locomotive, as the winder has perhaps to be stopped and started once or twice a minute. I cannot see any reason why liquid controllers should not be satisfactorily designed for electric locomotives. Reference has been made in the discussion to the grading of resistances for series motors. A graphical method is given by Arnold in "Die Gleichstrommaschine." In conclusion I should like to know whether any action has yet been taken with a view to standardizing electric traction on the railways in this country. In the past history of the railway service we had the battle of the broad and narrow gauges, but it seems to me that this will be overshadowed in the future when we have to co-ordinate the many different kinds of electric traction now being introduced into this country. It seems to me desirable that an attempt should now be made in this direction.

Dr. T. F. Wall: In Mr. R. T. Smith's paper* the conclusion was drawn (pp. 298–9) that for fast passenger service the continuous-current series motor is at a disadvantage compared with the steam locomotive, because the characteristics of the ordinary series motor is such that the torque diminishes too rapidly with the speed—the torque at low speeds being limited by the strength of the draw-gear. It seems to me, however, that by the use of a diverter to the field coils, the torque at the high speeds may be increased at will. If the supply pressure is constant the armature current at any given speed will be greater with, than without a diverter, whilst for a given speed the flux per pole will be practically the same whether a diverter be used or not. Consequently, the use of a diverter will enable the motor to exert a larger torque at a given speed. I should like to ask Mr. Lydall whether the control equipments for electric locomotives provide for the connection of diverters in parallel with the field coils.

* R. T. Smith. Some railway conditions governing electrification. *Journal I.E.E.*, vol. 52, p. 293, 1914.

Mr. F. Lydall (*in reply*): I gather from Mr. Carter's remarks that the question of the number of steps in which it is necessary to switch out the controlling resistances in order to keep the fluctuations of torque within certain fixed limits, is not very clearly understood. Mr. Carter agrees that the number is determined by the slope of the characteristic curve, but considers that the internal resistance does not enter into the question. On the other hand, he attributes the determining cause to the pressure-drop due to resistance. But if the internal resistance does not settle the pressure-drop due to resistance, I fail to understand what does. To a certain extent Mr. Carter is right, if I understand him correctly, when he implies that the degree of saturation has more influence in the matter than the internal resistance. Nevertheless I feel sure he will agree with me, on further consideration, that the deciding factor is the slope of the characteristic curve. But when he states that the determining factor is the permissible fluctuations of tractive effort during the accelerating period, he seems to miss the point altogether. The question is how many steps are necessary to keep the fluctuations of tractive effort within given limits? To say that this depends on the limits is like saying that the distance between two points depends upon how far they are apart. Mr. Carter quite rightly states that the number of steps in the control system on motor-coach trains is determined by altogether different considerations. May I suggest, however, that the principal consideration is not so much what the public will stand in the way of jerks, as what the engineer thinks they will stand.

Reference has been made by one or two speakers to the effect of self-induction in the starting curves. It may be that this effect is inappreciable in any case, even on a tramcar starting up very rapidly, but I doubt if any instrument other than an oscillograph would demonstrate this. My point, however, was not so much that self-induction is important in some cases, as that it produces no useful result in the case of a locomotive starting a heavy train on a steep gradient.

Replying to Mr. Poultney with regard to the use of an air filter on locomotives designed for forced ventilation, I am not aware of any case in which a filter is used. It is not likely that the air in front of a train will contain sufficient dust to make a filter necessary.

Full particulars as to the weights and capacities of the locomotives shown on the screen have been given in the paper published in Volume 51 of the *Journal*, to which

Mr. Lydall. I may refer Mr. Poultney. The same paper contains some information as to the cost of maintenance.

The question of comparative costs of steam and electric locomotives is not easy to deal with. The cost of an electric locomotive depends on a number of considerations—weight, horse-power, control scheme, electric system, etc. Small electric locomotives of the simplest kind may cost as little as £35 per ton, and the price per ton may be as high as £110 for main-line locomotives. With such a large variation it is practically impossible to deal with this question in a general way.

Dr. Garrard draws attention to the constant-current system and suggests that it might be used for traction purposes. One cannot say that this is impossible, but it would undoubtedly introduce undesirable complications in the way of a double-pole overhead line divided up into insulated sections, and various automatic arrangements for short-circuiting the two poles on any section of the line not occupied by a train. Against these and other disadvantages it is very doubtful whether any substantial advantages can be claimed, and I am not aware that the proposal has ever been seriously taken up. Of course, the use of the constant-current system for power transmission to traction sub-stations is quite another question, and does not come within the scope of the present discussion.

Dr. Garrard's experience with cast-iron grids agrees with my own. It certainly seems to be the case that the shocks which they have to stand at the hands of the goods department are far worse than those they experience when once they have been installed in the locomotive.

To my mind the difference between the working of a locomotive and of an electric winder is quite sufficient to account for the infrequent use of liquid rheostats for traction work. It may be quite true that a winder has to be started and stopped once or twice a minute, but this represents ideal conditions compared with what a locomotive may have to do. A locomotive may have to start three times in half a minute with any load up to the maximum and with any conditions of track. The one case is distinguished by almost perfect regularity, the other by extreme irregularity. The whole difficulty with locomotive control resistances is not the grading, which is after all merely a question of calculation by one method or another, but the determination of capacity, which is in reality a matter of intelligent anticipation or foresight.

Manchester Local Section, 10th March, 1914.

Alderman Walker. Alderman W. Walker: I should like to approach this matter from the point of view of standardization. I am not competent to deal with the technical details in this paper, and few people in Manchester have had an opportunity of seeing an electric locomotive under construction or in operation; whilst opportunities, at any rate my own, of observation on the Continent have not been many. On page 384 a remark is made which points out one advantage of electrification. The author says a moderate speed for an electric locomotive is one of from 60 to 65 miles per hour. If this is only a moderate speed, there is a very good case for the adoption of such a locomotive, as it is believed that the speed of steam locomotives has now reached its limit, and that any increase of the average speed will enable the existing lines to deal with a greater number of trains per mile. On page 386 are two drawings which should to some extent help to indicate the electrical system to be adopted. They are presumably drawn to the same scale, one being that of a 2,000-h.p. and the other that of a 800-h.p. motor, and where space is so limited the advantage can clearly be seen, other factors being equal, of using the motor giving the greatest power for the space occupied. I should like to ask the author if he knows whether there has been any necessity for filtering the air required for the forced cooling of motors owing to the presence of dust, which is so marked a characteristic of our railways. The Chairman referred to standardization, and I know that eminent leaders of the electrical profession take the view that each manufacturer ought to be free to persuade the buyer to adopt his own particular system, as experience will thus be obtained, and should the installation prove to be faulty it can be "scrapped" and another substituted. Taking a short-sighted view, this may appear sound to the manufacturer, but failure on even a small section of railway will do much to prevent, or at least retard, further progress for some time. I wish to approach this subject from quite a different point of view, namely, that of the general good of the country, and I think that the competition to obtain orders for any and every system, wherein financial arrangements may weigh as much as technical excellence, will not give the best results, or in the end be good for the manufacturer. The idea that a railway company may be willing to spend hundreds of thousands of pounds in order to install an electric service and to be obliged to admit in a comparatively few years that a mistake has been made, and that it must be "scrapped" to be replaced by the system of another manufacturer, is one which cannot for a moment be put forward as a business proposition. Plant will have to be retained in order that it may earn sufficient to defray its cost, or a large proportion of such cost will have to be borne by the plant which supersedes it. I would ask this Local Section to urge upon the Institution the necessity of taking steps to obtain the appointment of a Committee to advise with regard to experimental work, to tabulate and consider the results obtained, and above all to endeavour to secure a national system under which all rolling stock will be able without alteration to run over every railway in the kingdom.

Mr. Wheelwright. Mr. P. P. Wheelwright: My regret is that no British manufacturers seem to have had much experience of, or made many motors for use in conjunction with, the electrification of railways, and that the railway companies in this country apparently still refrain from going into the question. The question raised by Alderman Walker is one of great importance, and I agree that until British railways have discovered a system suitable for dealing with the great variety of traffic on all their lines, it will be impossible to standardize. Individual companies cannot afford in these days of increasing expenditure to spend large sums of money in equipping experimental lines, and future practice will no doubt have to be based on the

collective data obtained, which will eventually be available for standardization on sound principles.

Dr. E. Rosenberg: The author says that in only one or two cases, principally for three-phase locomotives, liquid resistances have been used, but I would mention that they have been used in the electrification of the Italian State Railways, where there are 140 locomotives either in operation or under construction, with a total capacity of over 300,000 h.p. An interesting application of forced ventilation for rheostats is in use on some rack and pinion railways in Switzerland. In going downhill the motor is used as a generator, and the energy is consumed in the resistances, which are cooled through a large fan mounted in the cab. I should like to make a few remarks with reference to the question of standardization raised by Alderman Walker. At the occasion of a recent dinner he expressed the opinion that no railway company would undertake electrification of a part of its lines unless it were satisfied that the same system was suitable for the electrification of the entire system, and that if different railway companies were to adopt different systems a state of chaos would result which would prevent through-running, and hence that not a single mile of railway should be electrified until a conference of railway men, electrical engineers, and public authorities, has decided on the one system which would be suitable for the electrification of all the British railways and which, therefore, should be adopted by all. I should consider such a step to be disastrous, because I am convinced that such a conference could not agree at the present time, and that it would postpone electrification indefinitely. My opposition is certainly not based on the belief that it is in the interests of a manufacturer to install apparatus which has to be "scrapped" after a few years, giving him the opportunity then to install a new system to replace the old one. There is no manufacturer who likes to see his own apparatus "scrapped," and it is common knowledge that he can ultimately obtain far more business if it is known that his apparatus will do service for 50 years rather than require renewal after 5 years. Nothing would suit the manufacturer better than standardization of a system if he could hope that such standardization could be achieved, and that it would remain in force for a long period of years; but I consider it to be a hopeless task to bring about standardization now. Some railway engineers will consider nothing but single-phase current; there are others who pin their faith to low-tension continuous current, and still others who think high-tension continuous current the only promising system. Certainly as regards high-tension continuous current, matters are in a state of development. When an important firm of consulting engineers in this country reported on the electrification of the Melbourne railways six years ago, it proposed a third rail and continuous current at 800 volts. The electrification was not carried out at that time, but now the same engineers have proposed an overhead line with continuous current at 1,500 volts, and this has been adopted by the Australian Government. The Lancashire & Yorkshire Railway, which electrified successfully several years ago the Liverpool–Southport line with continuous current at 600 volts, thinks now that a high-tension system would be an improvement, and it has chosen a pressure of 1,200 volts for the electrification of the Manchester–Bury line, and has also experimented on a small scale with a pressure of 3,000 volts. Electrification at 1,500 volts continuous current has proved a complete success in America, and a pressure of 2,400 volts is now used on a few lines. There is no doubt that high-tension continuous-current electrification will prove profitable on certain lines where a 600-volt system would be too expensive. On the other hand, the London & North-Western and London & South-Western Railways, which are now electrifying their suburban lines with frequent traffic, could not do any better than adopt the 600-volt third-rail system. This they are adopting because it enables them to obtain through communication with the Metropolitan and Underground Railways. Nobody will assume that the London & North-Western Railway when choosing a pressure of 600 volts for the Watford line was of the opinion that the same system could ultimately be used for running express trains and goods trains over its entire lines to the north. I see no deplorable chaos in electrifications going on at present, but rather sound commercial undertakings and healthy engineering experiments. There is no better way of experimenting than by letting those who believe in a competitive system show what this system can do. The electrification of the whole of the British railways will not come to pass in the next 10 or 15 years, and all the developments and improvements which will take place must not be foregone by prematurely standardizing, even if such standardization could be agreed upon, of the impossibility of which I am firmly convinced. If electrification be undertaken now, and the equipment has to be "scrapped" after 10 or 15 years, it is not really wasteful. On a suitable line electrification will pay for itself during such a period. I fully believe that standardization will ultimately be effected, but an ideal, unattainable for the moment, should not stand in the way of present progress and healthy activity.

Mr. W. Cramp: The author has mentioned that the maximum torque desirable is one sufficient to cause the wheels to skid. Is it not unscientific to limit the torque to that which shall be capable of causing the wheels to skid? Does not the point at which the wheel will skid depend on the number of wheels, their diameter, and the weight on the wheels. How then is it possible to determine the question by the use of such an arbitrary rule? Why should the wheels be used as an overload cut-out? The horse-power of the motors quoted seems to me to be excessive. The Lötschberg Railway is stated to possess a locomotive with two 1,250-h.p. motors mounted on it for dealing apparently with passenger traffic. Will the author say what is the rating of these motors, and also how this horse-power compares with that of a steam locomotive for similar work. As to the question of gearing, some few weeks ago I saw some back numbers of the *Auto-Car*, and in them can be seen the horseless vehicle in various stages of its development. To-day the electric locomotive is being developed, and the process appears to me to be very similar. The rotatory motion is being transmitted by reciprocating connecting-rods. No doubt there is a good reason for this, yet one cannot help thinking that it should be avoided. Enormous developments have been made in gearing by motor-car manufacturers, and it is now possible to secure a very high efficiency with a

Mr. Cramp. worm gear giving a very high power. Perhaps the author will be able to explain what has been done in this direction and why worm gearing cannot be used for locomotives. What determines the diameter of the locomotive wheels; and why has there been in the matter of wheel diameters an imitation of steam locomotives? There is nothing to limit this dimension, so far as I can see, except the characteristics of the motors. With regard to Ward-Leonard gear, I should like to mention a locomotive built by the North British Railway Company in which a steam turbine, boiler, condenser, dynamo, and motors are all on one truck. The locomotive has run a number of miles already, and the simplicity of control is very noticeable. Has the author any comparison between such a machine and those which have been illustrated to-night? On page 391 there is a very interesting statement concerning resistance grids. The author points out that in grid resistances a thin coating of aluminium paint, while protecting them from oxidization, seriously impairs their capacity of radiating heat. This fact is new to me and I believe it is not supported by evidence, provided that the paint is properly applied. I should like to ask him if he has any results of tests in support of his statement. It is evident that the centres of gravity of the locomotives shown on the screen are very high. This may be a serious disadvantage, not only in necessitating an alteration to the banking of our railways, but also in rendering it likely that accidents may occur at curves. The motors shown in the slides have an unduly large number of brushes. Cases have been known in ordinary work where the cost of brushes amounts to hundreds of pounds per annum, and it seems to me that the renewal of brushes with these locomotive motors will be an important item. It is very interesting to hear that steam heating is adopted in the trains, and that the method used is that of heating water by electricity. But why put heat units into water when by means of radiators the carriages might be warmed directly? Finally, it seems to me that advantage might be taken of the air movement set up by the train itself to secure proper ventilation of the motors, etc. Is it not possible to arrange the air passages so that air shall be delivered by the movement of the train through those parts which most need cooling? In the diagrams there is no evidence of this being done.

Mr. Maybury. Mr. P. T. Maybury: I should like to make one suggestion with regard to gears. One of the advantages always claimed for the electric motor when it is proposed to be installed in any power scheme is its uniform turning moment. I believe this to be quite as important in relation to electric railways as in any other application of the electric drive, and would suggest that such things as cranks and connecting-rods are quite out of place when used for transmitting circular motion to circular motion, and that either direct drive or a drive through spur, worm, chain, or belt gearing is the proper system to adopt. In this connection it would be of interest to know whether steel belts have ever been tried. In a paper read before the Manchester Association of Engineers a few weeks ago figures were given of the results of some tests on steel belts, and it would appear that these have practically an unlimited life and an efficiency of transmission of the order of 99 per cent, as against the 97 or $97\frac{1}{2}$ per cent efficiency of spur gearing. The width of a steel belt is only about one-half that of a leather belt of the same transmitting power. I should also like to ask the author whether the motors have ever been fitted with their shafts vertical in order to dispense with the gyroscopic effect when rounding curves at high speeds. The motors could be geared through worm gearing, as suggested by Mr. Cramp. Mr. Maybury.

Mr. Moffet. Mr. J. L. Moffet: A third choice to the two methods given on page 384 of increasing the motor power where space is limited is to increase the motor speed and to use a larger gear ratio. This method is used to increase the capacity of the motor which can be installed on a standard motor car; it will usually be found that where continuous-current motors of greater than 150 h.p. are installed, the extra power is obtained by running the motors at a higher speed at their one-hour rate. In connection with the author's remarks on pages 387 and 388, I should like to ask whether the limiting load that a locomotive can handle is not fixed by the load that it will start, rather than by the load that it can accelerate, since the resistance of a train at starting is considerably higher than when moving. Professor Perry gives the resistance at starting as 20 lb. per ton, compared with 5 lb. per ton at 5 miles per hour, whilst in some tests carried out by Thurston on journals he found that the coefficient of friction at rest was 0·14 as against 0·005 when rotating, with pressures such as occur in railway work. This effect will also have been noticed by anybody who has moved a railway truck by manual labour. I think that the author has not taken this into account in obtaining Fig. 5. Using the curves given in Fig. 6, the following figures can be obtained:—

Starting tractive effort per ton on 1 in 90 gradient $= 20 + 25$ lb.
Maximum tractive effort of motor $= 4{,}500$ lb.
Maximum weight started on 1 in 90 gradient $= 4{,}500/45 = 100$ tons.
Resistance per ton just before going into 3rd notch $= 7 + 25$ lb.
Tractive effort of motor just before going into 3rd notch $= 3{,}600$ lb.
Accelerating force, $3{,}600 - 100 \times 32 = 400$ lb.
Acceleration just before going into 3rd notch $= 2\cdot5$ miles per hour per min.
Acceleration after going into 3rd notch $= 8$ miles per hour per min.
Average acceleration $= 5$ miles per hour per min.

Thus, if a locomotive will start a train on a 1 in 90 gradient it will accelerate it at 5 miles per hour per minute even with the moderate number of notches shown in Fig. 6. If the ruling gradient had been less steep, the acceleration would have been still higher. The point mentioned on page 389, namely, that the maximum motor current in a tramway motor during notching is reduced owing to self-induction is interesting. I should not have thought that the increase of speed of a tramcar would have been appreciable during the period that the current is choked back by self-induction. I should like to ask whether the dual control recommended by the author on page 396 arranged either for automatic or hand operation would greatly complicate the control gear.

Mr. Lydall. Mr. F. Lydall (*in reply*): Dr. Rosenberg has raised the question of the advantages of forced ventilation of motors. The way in which I have looked at it is not so much

Mr. Lydall. a comparison between motors which have and motors which have not forced ventilation, as between the capacity of the motor on the one-hour rating and on continuous rating. One knows quite well that with most railway motors the ratio between the one-hour rating and continuous rating without forced ventilation is about 2 to 1, but in the case of forced ventilation the ratio is by no means the same. There are a good many figures in the paper which show that the ratio is very much nearer equality. I quite agree that there is a great difficulty in explaining one or two of the figures in the table of motors dealing with this point; the probable explanation is that there are two alternative methods of producing a forced draught, one of which may be called natural ventilation and the other forced ventilation.

With regard to liquid resistances, when I made the remark that these had been used in one or two instances I did not mean on one or two locomotives; I know that there are one or two railway systems which are using a large number of locomotives where these liquid resistances are employed.

Alderman Walker referred to the moderate speed of 60 to 65 miles per hour. It is perhaps not quite understood that the moderate speeds referred to are maximum speeds, that is to say, speeds beyond which the locomotive is not designed to run. It would be correct to say that speeds can be considerably increased by the use of electric locomotives. These can undoubtedly be built for a considerably higher speed than the steam locomotives in use at present on the same lines; whether this increase in speed makes electrification worth while it is impossible to say, as this is really a railway engineering question. He also raised the question whether filtering was necessary in the case of forced ventilation. I am not aware that it has been used. The air in front of a railway train is comparatively good; it is the air following the train that contains a lot of dust and dirt.

Mr. Cramp asked why it is desirable that the motors should be able to skid the wheels. It is desirable because if the motors are built to do this the driver cannot overload the motor beyond the point at which the wheels will slip. If it takes 200 per cent overload to skid the wheels, it would be quite possible to load the motors so that they would burn out. It is of course merely a question of the coefficient of adhesion between the wheels and the rails, but it is practical to say that if the motors are designed so that they are able without injury to skid the wheels with an adhesion of one-third, all that is necessary has been done.

The horse-power of motors on electric locomotives compared with the horse-power of steam locomotives is very high. In the table on page 397, under the heading of geared motors the one-hour output of each motor on the new Lötschberg locomotive with forced ventilation is 1,500 h.p., the continuous output being 1,250 h.p. I think also the various horse-powers mentioned in this discussion are also given in the original paper printed in Volume 51 of the *Journal*.

Coming to the question as to whether worm-cut gearing can be adopted, it is in general the intention of the designer to use a motor in which the peripheral speed is worked up to the maximum, and it is a question as to whether it is necessary to go to worm gearing to arrive at this result. In a good many cases there is no object to be gained by using such gearing. Single-reduction spur gearing is usually quite sufficient to meet all the requirements of the case. Mr. Lydall.

The reason why certain diameters of wheels are chosen depends entirely on the design of the locomotive. If the locomotive is of the coupling-rod type, the wheel diameter must be chosen such that the number of revolutions is not excessive at the maximum speed. On the steam locomotives the maximum number of revolutions of the driving axles is of the order of 300 revs. per min. If a locomotive has to travel at a certain speed it is a simple matter to calculate the diameter of the wheels to give this number of revolutions. The whole point in the design of the electric locomotive is that the piston velocity of the steam locomotive is eliminated. It has been found that the revolving cranks of electric locomotives can be run at a higher speed; they can be run up to perhaps 500 revs. per min. as a maximum. Having, however, accepted this figure as a result of experiments, if we are given any locomotive speed it is a simple question to ascertain the diameter of the driving wheel.

Reference has been made to the North British Railway Company's system in which a turbo-electric set is installed. This is a very interesting experiment, but I think it is scarcely likely to result in the displacement of the electric locomotive. The great advantage of the electric locomotive is that it is one of a number of units which are worked intermittently and which all take current from a power station at a considerable distance, and in this power station there is the utmost possible economy in generating current. I do not think that any turbo-electric locomotive is likely to enter into serious competition with the electric locomotive.

I have no figures at present available regarding the painting of resistances with aluminium paint.

When Mr. Cramp says that the centre of gravity of an electric locomotive is far higher than that of a steam locomotive I hardly think he is correct. In the Pennsylvania locomotives, where the motors are mounted high up in the cab, the position of the centre of gravity is stated to be within an inch or two of that of the corresponding steam locomotives. The difficulty in many cases is that the centre of gravity is so low. One of the great advantages of placing the motor in the cab instead of on the axles is that this difficulty is removed.

As to the number of brushes on the motors shown on the screen and the question of the cost of renewals of brushes, I do not think that this is a matter which is at all serious. It is one of those things which are obviously a disadvantage, but the importance of which must not be exaggerated. With these large single-phase motors the working of the commutator and the brushes as a whole is very satisfactory.

Steam heating on locomotives is in use in the States just as it is here. In the States the boiler is sometimes fired with oil, while in other cases it is fired by coke or coal, and on some locomotives on the Continent it is heated by electric current.

Mr. Maybury raised the question of steel belts, but I have no experience of these. I do not, however, believe that they would be of much use because of the irregular working of locomotives. The question was also raised

Mr. Lydall. whether it would be possible to use horizontally-mounted motors so as to avoid gyroscopic action. Theoretical calculations made on the Continent show that the gyroscopic effect is scarcely worth taking into account.

Mr. Moffet has criticized the starting curves shown in Fig. 5 because the extra high tractive resistance at starting has not been taken into account. The value that he mentioned, viz. 20 lb. per ton, seems rather high; if I am not mistaken the figure found by experiment on the Lancashire & Yorkshire Railway is about 15. But in practice this high resistance is only experienced when a train has been standing, so that the journals are unlubricated. It is generally possible also to get over this difficulty when it arises by setting the train back a little so as to lubricate the journals sufficiently to bring the tractive resistance down to about its normal value. Mr. Lydall.

Mr. Moffet also referred to the effect of self-induction in the motors. I called attention to this point more particularly to show that it was not to be taken into consideration in big railway motors when starting up a severe gradient. As a matter of fact it would be difficult to prove whether self-induction does or does not produce any appreciable effect in any case.

The cutting out of automatic acceleration is a simple matter. It is a matter of design of the apparatus, and so far as I know there is no difficulty whatever about it.

DISCUSSION ON

"SOME RAILWAY CONDITIONS GOVERNING ELECTRIFICATION." *

NEWCASTLE LOCAL SECTION, 23RD AND 27TH FEBRUARY, 1914.

Mr. Stoney. Mr. G. STONEY: There is a point that the author does not refer to, namely, the poor load factor in main-line working. I have long had the impression that until some form of storage is possible other than by means of the ordinary storage battery the electrification of main lines is more or less hopeless. Perhaps the author may be able to give us some information on that point.

Mr. Hunt. Mr. F. O. HUNT: On page 295 the author specially emphasizes the idea that suburban service may be engineered in a totally different manner from that of any other portion of the line to be equipped electrically. This comparative isolation of one section of the traffic from others is certainly a distinct help in the process of bringing about electrical working, but it should nevertheless be kept in mind that ultimately some similarity of method will prove to be an immense advantage when the process of transition is complete. This also has a bearing upon the "new capital" difficulty, which must to some extent be met by the gradual replacement of worn-out steam locomotives by those of the electrically-driven type. I am sorry that the author did not consistently use the term "electrical energy" rather than "electricity" when referring to the purchase of electric energy. On page 298 there appears some slight confusion of meaning in the terms "output" and "load." Presumably the former means "horse-power," while the latter refers to "tonnage" hauled. The reason no electrically-operated locomotive suitable for high-speed traffic has been produced is because the whole demand has hitherto been for the rapidly accelerated train travelling at a moderate speed. There appears to be no insuperable difficulty in complying with the conditions laid down. I have been somewhat surprised to notice the tendency in Continental designs to introduce complex gearing of various kinds between the motors and driving wheels. This seems like a repetition of the early history of steam locomotion, from which can be learnt the importance of striving after the simplest form of the transmission of power from the source to the driving wheels. Mr. Swinburne's lament of 13 years ago "that electrical men were not railway men, and vice versa" is emphasized in this paper. For instance, none but the man with railway experience could fully appreciate the importance of considerations such as the strength of draw-bar gear and the lay-out of sidings in determining the design of goods locomotives. In regard to the shunting locomotive, the author considers that the chief hope lies in the single-phase locomotive, but I would suggest that the possibilities of series-parallel working can hardly be considered to have been exhausted, and also that in making comparisons it must be remembered that even the steam locomotive carries out the very slow movement of wagons under extremely inefficient conditions. A point of considerable importance is alluded to in the last paragraph of the paper, *i.e.* the possibility of obtaining ample adhesion while concurrently the weight per axle is greatly reduced. This, together with perfection of balance due to the elimination of reciprocating parts should be a source of considerable economy in the upkeep both of track and locomotives. Mr. Hunt.

Mr. S. G. REDMAN: I am somewhat opposed to considering railway electrifications as for distinct and separate classes of traffic as the author does, mainly because so much of the capital cost of installing either could be made common to all. In England our big towns are close together compared with those of America, and the suburban traffic of one such town extends so as almost to become connected with that of another. Hence over large areas the service might easily consist of trains of one general type, operated as stopping and non-stopping trains as the demand requires. The author refers to the possibility of increasing the traffic facilities by electric traction without extending the way or works, and the Tyneside electrification is an instance. Under steam working the traffic demands had not made it worth while increasing what was a comparatively open service; under electric working, on the other hand, the traffic demand has increased beyond the possibility of steam working (without additions to the Mr. Redman.

* Paper by Mr. R. T. Smith (see pp. 293, 368, and 465).

permanent way and works), and the rateable value of the seaside towns served has increased by from 60 to 70 per cent since the inauguration of electric working. Although the service has been most popular and the train mileage had been more than doubled compared with what it had been for steam working, it is interesting to note that the actual car mileage has not been appreciably increased. The basis on which the author compared the costs of steam and electric working is of much interest, and generally confirms my opinion that if the cost of electricity for the electric machine could be arranged so as to balance the cost of coal and water for the steam locomotives, the saving in the repairs of the steam locomotives would pay the capital charges on the electric equipment of the railway. The cost of 3d. given by the author for coal and water per steam train-mile is lower than I have generally considered it to be; perhaps the author will state whether this is for any selected services. The continuous-current equipment with series-parallel control certainly labours under disadvantages for heavy shunting work; but where this is occasional duty only, it might still be preferable to tolerate these disadvantages rather than to provide the complication necessary to avoid them.

Mr. Vesey Brown.

Mr. C. S. Vesey Brown: The note of complaint in regard to competition by municipal tramways is one which has been regrettably introduced. The facts have to be faced by the railway authorities. The railway is run for the purpose of conveying the public under certain specified conditions of tenure. As a member of the public I want to get from A to B as quickly and cheaply as possible, and those who undertake to carry me must see that their own arrangements as to remuneration, etc., are in accordance with their ideas of profit, etc. I agree that this may possibly be a "condition governing electrification," but those responsible for the management of the railway know the terms under which they are authorized to carry passengers and goods as well as the competitive terms on which tramways are allowed to carry passengers. They must naturally move accordingly. With regard to the suggestion of a differential tariff, I have often thought that railway companies might adopt such a principle for season-ticket and regular passengers, *i.e.* a fixed rate per annum between their residence and place of business plus a small sum per journey taken. It may be difficult to fix such a tariff, but it is not impossible to do so. Respecting the credit of British railways, has not the "low point" to which the author refers been induced by the attractions for the employment of capital elsewhere, having regard to greater security of tenure and the use to which the person using the money applies it? Mr. Redman mentioned the classification of passengers into "suburban" and "long distance." I agree with him that in this country there is little to choose between them. The average distance between most large towns is not 25 miles, and this is negligible for a "suburban" service. It is not too much to consider an hourly service to York or London instead of the 2- and 3-hour service with crowded trains that at present exists; and then the 1,100-h.p. locomotive of which the author speaks will be split up into smaller units. With regard to the cost of current, which the author puts at $\frac{1}{8}$d. to $\frac{1}{2}$d. per unit depending on the service required, it is to be hoped that those railway companies who are equipping their own power stations or who are purchasing electrical energy will some day publish figures showing what is the cost of generating the energy. It is quite an easy matter for a railway company to say that the cost should not exceed x pence per unit otherwise the steam-driven train is the better paying proposition; but the question when buying energy is how to fix a price which will cover fair remuneration to the capital employed as against that at which the railway company can itself generate at its own power station. When figures showing this latter part can be produced, the question of price at which to buy will be easily answerable.

Mr. Hawthorne.

Mr. W. Hawthorne: One frequently sees it stated that England is behind-hand in adopting electric traction on railways, but this backwardness ensures the benefits of the experiments in electrical operation made by other countries. Hitherto this country has not been committed to any system of electrification for general use, and it can profit by the experience of those countries which have already selected a system. Italy, for example, has largely adopted the three-phase system, Germany and Switzerland have decided on the single-phase system, whilst the United States seems to be inclining towards the high-tension continuous-current system. In the meantime England has only adopted electric working on urban and suburban lines, and is free either to let these develop naturally into inter-urban working or to select a different system for main-line and freight traffic. In view of the possibility that the latter course may be found desirable, it is important when deciding upon a system of suburban electrification to arrange the track conductors in such a position that they shall not interfere with the conductors of the system ultimately selected for main-line working. Reference has already been made to the close spacing of large towns in this country, and it is this fact which holds out the prospect of a natural development of electric traction on the lines along which a start has already been made. Suburban traffic can roughly be divided into three classes. First, the station-to-station traffic within the city; in London this covers an area within 5 or 6 miles of the centre, and is dealt with by the Tubes. The next zone extends from 6 to 16 miles outwards, and ought to be served by rolling stock more roomy and comfortable than the urban stock. Thirdly, there is the zone extending from 16 miles outwards occupied by people who can afford both the time and the money for a couple of daily journeys lasting up to 45 minutes each. To encourage traffic from this zone the railways must provide a rapid service with few intermediate stops, and coaches approaching in comfort the standard of main-line stock. From an operative point of view the railways will have to solve the problem of running these three services on existing tracks, or will have to build new lines into the centre of the city. The limit of the third zone will often be found in this country to be within the sphere of influence of another large town, and the high-speed suburban service will develop naturally into an inter-urban service. Incidentally it might be permissible to point out that the author on page 295 gives the maximum number of trains per hour on the Tyneside lines as six. This is not quite correct. The closest schedule is five trains dispatched over one track in five minutes; the maximum for one hour is 14 trains. The author lays considerable emphasis on the importance of reducing the

Mr. Hawthorne. generating costs in order to keep down the total cost of power; but there are other ways of doing this. The coach designer can help by reducing friction losses and keeping down the weight hauled per passenger-seat. Something may also be done by some form of storage or regeneration whereby a portion of the energy now lost in braking may be available for the next start.

Mr. Hunter. Mr. P. V. HUNTER: The electrification of railways has now been a matter of interest and discussion among electrical engineers for some years. The subject has only too frequently been discussed from the limited technical aspect as it presents itself to the electrical engineer. No doubt one object in the minds of those writing upon and discussing the matter has been to further the cause of railway electrification; it is, however, greatly to be feared that in this respect the result has been negative. In dealing with the question as a railway problem rather than as an electrical one, and reviewing the conditions from the railway point of view, the author has made a valuable contribution to the subject. He has succeeded to a degree which would hardly have been thought to be possible in making a financial comparison of steam and electrical operation. As was to be expected, such a comparison does not show any very decided advantage in favour of electrical operation. This is, however, a position in which electrical engineers are accustomed to find themselves in the majority of the applications of electricity. It is, I think, quite a frequent experience that electricity does not show a very substantial advantage on paper compared with its competitors. On the other hand, the financial advantage invariably materializes when the conversion has been made, and there is every reason to think that railways will not form an exception to this general rule. The probable explanation of the bad showing of electricity is that the cost of electrical service can be estimated more readily and more accurately than the actual cost of an existing service given in other ways can be ascertained. In other words, when electricity is applied unexpected economies occur. I may cite as an instance the question of painting. It would not, I think, be reasonable to ask anybody to estimate the saving to be expected in the painting of railway stations on account of electrical operations, yet anybody who takes the trouble to examine the conditions of the Newcastle Central Railway Station and to compare that section into which electrical trains run with that into which the steam trains run, will readily agree that a substantial saving should result. I believe, and have no hesitation in saying so, that many unexpected and material savings of this kind would occur under electrical working. Another side of the question is the increased traffic likely to accrue from the flexibility of electrification. It would not be reasonable to expect the traffic department of a railway to form a rigid estimate of the value of a more frequent main-line express service, but since such a service could be given as cheaply as a less frequent one having larger trains it would be adopted, with the result that increased revenue would be obtained. The working of the goods service electrically would relieve congestion which might otherwise occur on account of the greater frequency of express trains. It is unfortunately true that steam and electric service cannot be properly compared, as the natural method is to compare an electric service under steam conditions; whereas the two services would differ in character considerably.

Mr. Hunter. On the purely engineering aspect of the matter I note that the author limits his attention to tractive equipments, and rightly so, as the remainder of the electrical equipment is a matter of everyday use for purposes other than railway traction. I have not personally worked on this part of the equipment, and it comes somewhat as a surprise to me therefore to find that a motor with a series characteristic falls so far short of what is required for express and goods services. In the case of the express service it is, I gather, at least necessary to develop economically a constant horse-power during starting, this being the ideal which the designers have set themselves to achieve. The straight series motor falls a good deal short of this ideal, but there is not the least doubt that some improvements, such as field control suggested by the author, will enable it to satisfy the requirements. There is, however, no reason why electrical engineers should limit themselves to constant horse-power. It seems to me that if it can be done economically the proper course is to have a constant draw-bar pull up to some speed approaching the maximum. Care should, however, be taken to avoid extremes in this direction, as expense may be incurred without material benefit. Railway engineers will, I think, agree that such a characteristic if obtained would be of value in that it would allow of a high average speed with a low maximum speed. From the point of view of maintenance of the track it is, I understand, important to limit the maximum speed as much as possible. The problem of goods working as described by the author is evidently difficult; it can be met completely by the Ward Leonard system. Such a system would enable the locomotive to meet satisfactorily and with a high efficiency any of the extremes of duty described by the author. Series motors with resistances will no doubt meet the service, and it is, I take it, a question of cost *versus* economy. I think there is no substantial objection to a motor-generator on the locomotive. I feel sure that it would take less attention from the driver than the equipment of the present steam locomotive. If such a system were adopted for goods service it is perhaps questionable whether it would not ultimately be found advantageous to use it for passenger service also (apart from urban and suburban work). Possibly in such a case the same locomotive would meet both services, or in any case, passenger and goods locomotives would be interchangeable for the service of either to a degree at least equal to that now obtainable in steam locomotives. In conclusion, I would plead for an attempt to standardize one expression for "acceleration." It is now most confusing to those who are not constantly dealing with the terms to have continually to be mentally translating "miles per hour per second" into "feet per second per second" and vice versa.

Mr. Prescott. Mr. C. W. PRESCOTT: Mr. Hawthorne mentioned electric braking from the point of view of regeneration. There is another aspect from which it may be viewed, and that is its usefulness in reducing both the service and emergency stopping distances. With signalling arrangements where train stops are used for the purpose of automatically applying the brakes and cutting off the power should the driver overrun a signal at danger, such as are employed on the underground systems in London, the minimum distance possible for unchecked running between the head of one train and the tail of the one preceding it is twice

the emergency stopping distance plus the service stopping distance; and hence anything which can be done to increase the efficiency of the braking of trains and therefore to reduce these distances will enable either a larger number of trains to be run at a given schedule speed, or the same number of trains to be run at a higher schedule speed for given track conditions. The retarding effect of the mechanical braking is least effective at the higher speeds, but it increases as the speed diminishes. The retarding effect of electrical braking is a maximum at the higher speed and diminishes with the reduction of speed. It would seem, therefore, that if a combination of the two could be used, the present retardations could be improved without increased inconvenience to passengers. It would appear that the question of braking, in the case of electric railways at least, has been largely left by the electrical engineer to other people, but there seems to be a distinct field of usefulness in this direction.

Mr. J. R. BEARD: The author emphasizes the fact that estimates of the effect of electrification on capital and operation charges can be made very exactly. This is an important point since railway estimates in the past have necessarily been more in the nature of approximations, and unless railway managements realize that electrification estimates can be trusted within close limits, there is a possibility that sound electrification schemes may not be adopted. In considering any electrification scheme it always seems to be assumed that it is not a paying proposition unless the additional gross profit is not only sufficient to pay capital charges on the cost of the conversion but also, as the author puts it, to give an immediate return on the old capital. In electrical operation the capital charges constitute a greater percentage and the operation charges a less percentage of the total costs when compared with steam operation; and whereas capital charges when once incurred are fixed, operation charges are, as the author points out, continually on the increase—a fact which is strikingly shown by the reports of the various railway companies for the past year. Consequently if electrification can be shown to increase the gross profit sufficiently to meet the additional fixed capital charges, it would seem justifiable even though there were no immediate net surplus, since, as operation charges in the course of time grow proportionately larger, an increasing net surplus is gradually obtained as compared with the corresponding results which would have been obtained under steam operation with its higher percentage of increasing operation charges. The author's investigation into the financial result of electrification of the complete passenger service on a large railway system is very interesting, but it seems to me to be inconclusive, as he appears to charge the whole capital cost of the track equipment, sub-stations, and distributing cables, against the fast passenger service. Of the three classes into which the author divides railway traffic it is generally agreed that the fast passenger service is that which would show the least favourable return from electrification. Consequently if a large railway system were completely electrified it would not be for the fast passenger traffic only, and a large proportion of the capital cost would be charged against the goods traffic and the suburban traffic. The author may have already taken this point into consideration, but if he has not, it would be interesting to know how it would modify his figures. In discussing goods and mineral traffic mention is made of the ability of the electric locomotive to haul up to the maximum strength of the draw-gear at more than double the speed possible with a steam locomotive. This is an important point, as owing both to the increased speed and to the greater facility with which goods trains may be interpolated between passenger trains, much greater use can be made of the large capital already sunk in permanent way and rolling stock. It is difficult to place any definite value on this, but in certain cases it may be one of the strongest arguments for electrification.

Mr. J. A. ANDERSON: With regard to the loss of power in brakes and resistances after the plant is installed, most of the capital charges and some of the running charges could be neglected in calculating the cost of the units lost. In that case the cost of power lost is something like 1/10d. per unit, so that the question of the waste in braking, etc., does not appear to me to be very important.

Mr. V. O. I. DAVIS: In Fig. 2 the author gives some curves showing the maximum continuous draw-bar pull for steam locomotives, and he also gives corresponding curves for continuous-current and single-phase electric locomotives. It is very interesting to notice that the shape of the curve for the single-phase locomotive more nearly approaches that for the steam locomotive than that of the continuous-current locomotive.

Mr. J. WRIGHT: On suburban passenger services the advantage of electrical equipment, compared with mechanical equipment, is the ease with which the draw-bar pull can be increased. At the same time it is very interesting to note that the steam locomotive is the main obstacle to the electrification of fast passenger services, in spite of the fact that it is very much handicapped by the distribution of its weight arising from the length of its boiler, and that the electric locomotive has the advantage that the ratio of the adhesive to the total weight is higher than in the case of the steam locomotive, and that the torque is quite uniform. In a paper which Mr. A. H. W. Marshall read before the Cleveland Institution of Engineers in January, 1911, he gave a curve which showed very clearly the uniform draw-bar pull of a steam locomotive as compared with an electric locomotive. He also said that there was as much as 20 per cent difference between the adhesion in the two cases. It seems very difficult to explain why the electric locomotive cannot compete with the steam locomotive for fast passenger traffic. I am surprised to note from Fig. 2 that the ratio of the adhesive weight to the total weight is about the same in the electric locomotive and in the steam locomotive. I should have thought that the electric locomotive would have shown to better advantage, but of course I do not know if the figures are comparable. I notice that in the paper which Mr. Lydall read a few days ago,* he pointed out that the difference in the ratio of the adhesive weight to the total weight in the electric locomotives, as compared with motor cars, has a considerable influence on the control. I should like to know why this is so.

Mr. G. N. WRIGHT: The author refers to the fact that the number of trains per hour can be increased by adopting track signalling. I suppose that means automatic sig-

* F. Lydall. Motor and control equipments for electric locomotives. *Journal I.E.E.*, vol. 52, p. 384. 1914.

Mr. G. N. Wright.

nalling. I should be glad if he would give the formula, if there is one, for the adhesive weight required in order that a certain draw-bar pull may be obtained. From the figures given in the paper it seems to be about four times that pull. Is that to be taken as a constant ratio? I suppose that with one double-acting cylinder, or two cylinders in parallel, the torque would be of the nature of a sine curve, and the necessary adhesive weight for an electric locomotive for the same draw-bar pull would only need to be $1/\sqrt{2}$ of that required on the steam locomotive. I am surprised that so much extra electrical energy is required where stations are very close together, and it seems a pity that railway companies cannot have the maximum-demand system of charging, so that those passengers who travel longer distances would get a cheaper rate per mile. I wonder if the Ilgner system is applicable to trains running between stations very close together. The author says: "the resistances to train movement increase in proportion to the speed raised to the 5/3 power." Is that figure obtained from tests only, or is it based on theory? It is also suggested that the addition of a shunt characteristic to the motors is worth consideration. Has this ever been done, or have series motors only been used so far? The trouble due to the reduction of the torque at high speeds could apparently be overcome to a certain extent by adding a shunt characteristic. Are there any special difficulties, however, in applying this method? I do not quite understand what the author means by saying that "large weights can be hauled if fitted with continuous brakes." It also seems that although it is not safe to use more than a certain draw-bar pull after starting, a greater draw-bar pull may be applied at starting. The author seems rather despondent as regards the likelihood of large electrifications being carried out in the near future, except perhaps for mineral traffic. I hope that this is not really the case.

Mr. Thompson.

Mr. P. S. Thompson: The author mentions two possible alternatives to the electrification of suburban lines; but as the cost in each case is prohibitive, the only course open to the railway companies is to electrify these lines, for on no other system could they run the 40 or more trains per hour necessary to deal with the traffic. This step should have been taken years ago when they had a monopoly; now they are being compelled to make this move in self-defence in order to retain their traffic in the face of severe competition. I agree with previous speakers that there should not be any serious difficulty in designing an electric locomotive to give a reasonable draw-bar pull up to speeds of 60 miles per hour. This is as high as should be necessary, for although the author says that the schedules call for 70 to 80 miles per hour, I do not know of any instance of steam locomotives running for any length of time at that speed. The average fastest "start to stop" run on 10 of our railways in 1913 was 57·8 miles per hour. The fastest run is that between Darlington and York, a distance of 44½ miles, at an average speed of 61·7 miles per hour. We know of course that in suburban traffic, at any rate near stations, the rapid acceleration and deceleration of trains have a very deleterious effect on the rails. In long-distance traffic, too, there is a certain amount of side wear and "battering" which has been attributed to the unsprung weight of the electric motors. From M. Parodi's paper* last year it would appear that the shock to the rails in the case of an electric locomotive running at the same speed as those considered above is regular and tends to become resonant. This is rather different from one's preconceived notions of what would occur in the case of a steam locomotive with its pounding action and an electric locomotive with its even turning moment. It has been estimated that about half a million tons of sulphuric acid are given off annually from the coal burnt in the Metropolitan area alone; this should give some idea of the damage caused to ironwork and buildings by the burning of coal. The decreased cost of maintenance of station ironwork, signals, tunnels, etc., should therefore be some inducement to the railway companies to adopt electrification. To my mind, the strongest argument in favour of the steam locomotive is that it is a single unit: a system consisting of a large number of independent units has the advantage of reliability. It is interesting to note that the author is in favour of the purchase by railway companies of electrical energy from those who specialize in the supply of electricity. He emphasizes that particularly in his paper, and we know that this is the only hope for the railways, if they wish to obtain their current at prices that would make electrification profitable. The author says that cheap coal is a factor making against electrification, but as it requires in order to do a certain amount of work twice as much coal when used in a steam locomotive as it does when the coal is burnt in a large power station and the power is transmitted electrically, the time will come when this factor will no longer operate as it does at present. One cannot altogether agree with the author's conclusion that an electric locomotive is unsuitable for shunting work. It has always been my impression that the more intermittent the service the greater is the benefit derived from the use of electricity for haulage and similar purposes.

* H. Parodi. Railway electrification problems in the United States. *Journal I.E.E.*, vol. 51, p. 526, 1913.

Mr. Duke.

Mr. A. M. Duke: The author's suggestion to use a separately excited field seems to overcome the chief objection, which appears to have been that the torque of a series motor falls off excessively at the higher speeds. A suitable characteristic has been obtained on tramway motors by shunting the field magnets on the last steps of the controller.

Mr. Edwards.

Mr. E. Edwards: The author points out many difficulties which stand in the way of a general electrification of the railways, and does not present the prospects of its adoption in the immediate future in too glowing colours. I should like to call attention to two of these difficulties. First, he mentions the dearness of money and the demands of labour; I think that since the paper was written the money market has eased considerably and the necessary capital could consequently be more easily raised. On the other hand, it is difficult to see in what way electrification would increase the demand for labour and thus have any influence on labour's demands. Another difficulty to which the author calls attention is the weakness of the draw-gear of the present rolling stock. This trouble does not seem very serious, and if the advantages of electrification are proved, surely it is possible to design draw-gear to take the increased strain and to secure the adoption of such gear on all rolling stock. There is one difficulty which the author has not brought forward, namely, the many different systems of railway electrification at present in use. It

ds. would seem desirable that electrical engineers should arrive at a consensus of opinion as to which system is most suitable for general adoption, and that this system should be standardized. In conclusion I should like to ask the author to what extent regenerative braking has been adopted in traction work.

lle. Mr. C. O. Brettelle: The author has made out a fairly good case technically for electrification, and the chief difficulty seems to be a financial one. The railways being of such great importance to the nation as a whole, I think the Government should help to provide the capital required for electrification. Mr. G. N. Wright adversely criticized Government control. The railway companies are often suspected of bureaucratic methods, and under Government control this unfortunate tendency would no doubt be very largely increased, which we certainly do not want. In Germany a number of electric power schemes have had their appeals for capital supported by the different States, and so have obtained the advantages of co-operative credit and company control, which seems to be a satisfactory arrangement. I notice that the railway companies allow about 6 per cent for interest and amortization of capital. I do not know whether that is due to conditions peculiar to railway accountancy, as it seems to me to be on the low side and thus to make out a more favourable case for electrification than is perhaps justified. I believe that the capital cost per mile of the British railways is $2\frac{1}{2}$ times as much as that of some Continental railways; this burden is partly an inheritance from early days and partly due to our being the pioneers in railway construction and having to buy our experience at a heavy cost. I see that in Berlin, at the average rate of $\frac{3}{4}$d. per passenger, they are unable to pay capital charges. I do not know whether they work under the same conditions as the electricity supply company, which has to hand over to the civic authorities 10 per cent of the gross profits before any other payment can be made. If so, perhaps this has more to do with the unsatisfactory financial position than the low average fare. In the case of the experimental line of the Lancashire & Yorkshire Railway, two motors are connected permanently in series. Are the field coils connected in series as well, or does the author merely refer to the armatures, a pressure of 100 volts being used for the excitation; *i.e.* are these motors compound wound, or are they separately excited? If the latter, the characteristic at starting would not be satisfactory. The author gives the cost of coal at 10s. per ton, and arrives at a total of £1,175, inclusive of capital charges, for the annual cost of a steam locomotive. He also mentions a cost per ton-mile, with coal at 12s. 6d. per ton. Is he taking the coal on the higher or the lower basis? I think he must have taken it on the lower basis. Mention is also made of the possibility of using single-phase motors with mercury-arc rectifiers. I think these are not yet in commercial operation.

an Mr. R. M. Longman: So far as I know there is no continuous-current railway system working with shunt fields, nor have regenerative systems yet been tried. It seems to be quite possible to use a shunt winding which is cut out at the start and is brought into use when very high speeds are required, that is to say for electric locomotives for high-speed passenger working. The tractive effort curves of electric locomotives will generally be sufficient for all the ordinary traffic except at the higher speeds, which only come into question in the case of long-distance non-stop runs. There is one point that has not been mentioned, namely, wind resistance. The design of an electric locomotive can be altered much more than that of the ordinary steam locomotive, so that a slight saving can be obtained in that direction. With regard to the track, on many lines considerable trouble has been experienced with hammering, owing to the irregular turning moment. At very high speeds there is a jumping action of the wheels, resulting in powerful blows on the rails. This question is sometimes very serious, but I do not see how it can occur with the even turning moment of the electric drive. The paper referred to by Mr. Thompson stated that the higher centre of gravity of the steam locomotive was an advantage. It is in one way, but not in going round a curve. It would no doubt be possible to support more of the weight on springs, in which case the electric locomotive would not damage the track. With steam locomotives, if more power is required the weight increases very much. It is the weight of these heavy steam locomotives which has such an important effect on the life of the permanent way, so that any economy that might otherwise be obtained is more than offset by the extra cost and maintenance of the permanent way. The specification for draw-gear evidently needs revision, and there is room for improvement in the structure of both passenger coaches and goods wagons. In connection with goods traffic, in America the brakes on all the wagons can be applied from the locomotive, whereas in this country the only brake is on the locomotive, so that the latter has to withstand the whole deceleration of the train. An important point is the necessity for larger power stations; but in any industrial district, by adding the railway load to the municipal lighting, power, and tramway load, the costs could be considerably reduced. Until something more is done on those lines there is not much hope for the electrification of the main lines. Of course London itself is an example of what should not be done, as a number of separate stations have been constructed for railway purposes. The question of the rating of railways is rather an awkward problem. If the rating of the railway is reduced, an additional charge falls on the locality. I should like to know why motor coaches cannot be used for some of the express traffic, and what are their disadvantages. The author refers to the cost of coal, which has increased since 1911. As it is not likely to fall to the level at which it was a few years ago, and as steam locomotives must not be allowed to burn an inferior quality of coal, this is an important factor in favour of electrification. One advantage of electric traction is that tests can easily be made, and that it is possible to know exactly what every part of the equipment is doing, so that the necessary steps can be taken to reduce the energy consumption and cost. Mr. Longman.

Mr. A. H. W. Marshall (*replying on behalf of Mr. R. T. Smith*): With regard to adhesion, there is no doubt that the coefficient is higher for electric locomotives than for steam locomotives, average values probably being 0·25 and 0·225 respectively. The weight on the driving wheels multiplied by this coefficient gives the tractive effort that can be exerted before slipping of the wheels takes place. In case of the electric locomotive or motor-coach train Mr. Marshall.

Mr. Marshall.

more wheels can be motor-driven, and thus greater tractive effort can be obtained than in the case of the steam locomotive, the limiting factor for the latter being the permissible weight per driving axle and the length of the coupled wheel-base, either or both of which would have to be increased in order to increase the tractive effort. A further limitation is, as the author points out, the strength of the draw-bar couplings. This also applies where only one electric locomotive is used, as the couplings have to be strong enough to transmit the total tractive effort. In the case of a train hauled by two or more motor coaches the combined tractive effort of the motors is not taken by any one draw-bar, so that a greater horse-power may be used. It is to this, I think, that Mr. J. Wright refers in connection with the influence of adhesion on methods of control. It has been established that a steam locomotive cannot be built to give the high rate of acceleration required for the operation of heavy suburban trains on a fast schedule, having due regard to the track conditions and safety in operation.

Very many attempts have been made to obtain regeneration while still retaining the ordinary series-motor characteristic, but I believe that these have not been attended with any great degree of success. With three-phase traction, however, in which induction motors are mostly used, the deceleration obtained by returning current to the line is an important feature, and is one of the principal reasons why this type of traction has been used on certain mountain railways in Northern Italy and elsewhere. I do not know what success has been obtained with regeneration on lines equipped with single-phase motors, although certain types of motors are said to operate fairly well in this respect.

Formulæ dealing with train resistance are all of an empirical character, and are obtained by taking the mean of a number of dynamometer tests carried out under conditions identical as far as possible with those usually obtained in the handling of any particular class of traffic. In connection with Mr. Longman's remarks, I think that there is not much to be gained by altering the shape of the front of the locomotive, as the effect of wind resistance is mainly felt as increased friction at the wheel flanges, caused by wind pressure against the sides of the train. With reference to the increased wear on the rails where electric traction is used, I have always thought that this wear showed up more for the reason that with an electric service the traffic is generally largely increased, and consequently the extra wear cannot be directly attributed to the difference between the methods of driving. It may be, however, that the smaller wheel in the case of the multiple-unit train, and the fact that the wheels are all of the same size, do cause the wear to increase to some extent, especially at points and crossings. I believe that this has been got over by using at these places a rail made of a harder steel.

With regard to the design of fast passenger locomotives, it seems to me that the author's suggestion to use a separate exciting winding might well be resorted to in order to improve the characteristic of the ordinary series motor for the very big range in speed and power required for express traffic. I should not have thought there was any serious difficulty in building a locomotive which would do all that was required of it, and the fact that no such locomotive has yet been built is not, in my opinion, any reason for thinking that the difficulty is in any way serious, seeing that so far there has been no demand for such a locomotive. I think it will be found that manufacturers are quite able and willing to meet any specification that the railway engineer provides.

Mr. Marshall.

Reference has also been made to the suitability of electric locomotives for shunting work, and I could point to several instances in this neighbourhood where ordinary shunting operations are carried out quite satisfactorily and with very great economy. In particular, the North-Eastern Railway have had two large electric locomotives at work now for upwards of 10 years, with excellent results. Seeing that shunting operations are an important consideration, more especially from the point of view of an interchange of traffic with large private works which have a number of locomotives of their own, I might refer to some costs relating to the existing methods of handling traffic in a number of large works in this district in 1911. The table given in a paper which I read on this subject before the Cleveland Institution of Engineers * shows that very large savings can be made by spending capital on the electrification of works' sidings, so that in course of time as railway electrification proceeds there is no reason why all goods traffic should not be handled electrically.

I am glad to be able, along with one or two other speakers, to agree with the author that it is to the advantage of railways considering electrification to purchase the power they require from a local power company. It is to the development of the larger power supply systems that I look for future progress in the electrification of railways, beginning with suburban services and ultimately extending farther afield with the express passenger traffic from one power supply district to another. It also seems to me that the question of system will ultimately be settled by the kind of current that power companies are best able to supply; and from this point of view a compromise is most likely to be obtained with the 1,500 and 2,000 volts continuous-current overhead system. I think that the price of current will be low enough to make suburban traffic possible, in spite of the low fares that are now the custom. If this is done, and capital is spent on equipping the tracks in the neighbourhood of towns, the extra capital expenditure required for faster and longer services will not be so serious for this class of traffic and will cause it to become a paying proposition. It should not be forgotten that the price of coal has increased during recent years, and is likely to increase still more, which of course makes the electrical case still better, seeing that less coal is used per track horse-power with electrically-driven than with steam-driven trains, the thermal efficiency of the former being from three to four times higher than that of the latter.

I am inclined to agree with Mr. Thompson that for the conditions which have arisen, under which the railway companies have lost a good deal of their short-distance traffic, they are largely to blame. This has been the principal spur to their doing anything as regards electrification. That this condition should have arisen has always been to my mind a sad reflection on the enterprise of the railway companies. It is scarcely conceivable that capital would have been spent so freely as it was on expensive

* A. H. MARSHALL. The use of electric locomotives for shunting purposes. *Proceedings of the Cleveland Institution of Engineers*, Session 1910–11, Table 21 facing p. 88.

tramway undertakings if at that time the railway companies had appreciated the advantages of a frequent service on their suburban lines, and had begun to use electric cars for these services. One can hardly understand why, until quite recently, steam locomotion was considered the only possible solution for railways, because the possibilities of electric driving were obvious enough as long ago as 1890. By 1895 electric traction was a commercial proposition, and yet we reach 1902 or thereabouts before even one of the larger railway companies makes a move, and then only owing to the pressure brought to bear by tramway competition. One would have expected the large railways, with their vast resources, to have taken part in the development of electric traction and to have produced something to suit their requirements. Had they done so, I believe that the unfortunate question as to which is the best system of electrification would not have retarded progress in the way that it has done during the past 10 or 12 years. I think railway engineers having first-hand experience would have got to know years ago what system best served their purpose. There is, however, one instance of electrification being undertaken not by force of circumstances but by an endeavour on the part of the railway company to avail themselves of the good points which electric driving possesses. I refer to the mineral traffic electrification scheme which the North-Eastern Railway Company is now completing.

Mr. R. T. SMITH (*in reply*): Mr. Stoney, referring to the poor load factor of such low-density traffic as obtains on main lines, suggests that some other form of energy storage than that provided by the storage battery is required. The author holds that for reasons other than poor load factor main-line electrification for passenger service is not in sight, but Mr. Stoney's point is another argument in favour of the railways purchasing electricity from a supply with such a diversity of load that the coming on and off of an infrequent railway traction load would be unimportant.

Mr. Hunt's criticism of a certain looseness in the use of the terms "output" and "load" is welcomed. The consistent use of the accepted terms is most important. The author is, however, not sure that the use of the single word "electricity," as short for "electrical energy" where the context can leave no doubt as to what is meant, might not with advantage become one of the accepted terms. In common with Messrs. Redman and Vesey Brown, Mr. Hunt criticized the division of passenger traffic into urban and suburban and main line. From the point of view of the electrical engineer there is no doubt that the distinction might very well be considered merely as one of density of train service. But from the economic point of view it is very convenient to distinguish between the suburban type of stopping service and the fast passenger type of non-stopping service. The suburban type may be defined as a service in which, if a reasonably high average speed is to be obtained, the actual speed is continually changing. There is the rush up to the maximum speed, and the rate of acceleration determines the power used. The maximum speed reached is continued for a shorter or longer time as required by the distance between stops, but for the highest schedule speeds used in this country the maximum speed is only reached in time to cut off current and apply the brakes either at once or after a little coasting. This applies to stops up to about 1 mile apart. For stops $1\frac{1}{2}$ miles and over, say up to 2 miles apart, the speed is only constant during such time as the maximum speed is maintained. At all other times during accelerating, coasting, and braking, the speed is constantly changing, and there are very few suburban systems, with a train density justifying electrification, where the average distance between stops is as great as 2 miles. The general character of such a service is a change of speed in which the rate of change is rapid. The main-line non-stopping type of service may be defined as one in which the speed changes during a comparatively small portion of the time between stops. The ideal is to run at the maximum speed for the longest possible time. In any service worked electrically the most wasteful use of power is where the speed changes rapidly, both during acceleration and during deceleration; the most economical use of power is when the speed is kept constantly at its maximum value. Although merely a matter of mechanics, railway men have only learned this through the ease with which electrical measurements can be made, and the author believes it to be of considerable importance that the economic distinction between these two classes of service should not only be made but be insisted on. It must always cost more to carry a passenger in a stopping service than in a non-stopping service.

Mr. Hunt has himself added to the reasons given by the author for claiming that the high-speed electric locomotive suitable for fast passenger service has not yet been produced in pointing out that designers are not yet agreed as how best to transmit the effort of the electric motor to the driving wheels. For low train speeds toothed gearing is quite satisfactory, but as train speeds increase the maximum limit of pitch-line velocity is soon passed, and some other method of transmission, either combined with toothed gearing or without it, becomes imperative. This, and its effect on the most economical peripherical speed of the armature, is very fully treated in Mr. Lydall's paper on Electric Locomotives.* In general, toothed gearing transmission implies a low centre of gravity for the locomotive, which while admissible at low speeds becomes most undesirable at high speeds.

Mr. Redman, in addition to deprecating the dual classification of passenger traffic, considered that the cost of 3d. per passenger train-mile for coal and water was too low. The published accounts do not separate locomotive running costs into passenger and goods traffic, but the cost for the four longest railways in 1913 with the present inflated price of coal varied between $4\frac{1}{2}$d. and 6d. per train-mile for both passenger and goods. The coal per goods train-mile is nearly if not quite double the coal per passenger train-mile, and the author has taken, rightly or wrongly, coal at 12s. 6d. per ton for a calorific value of 15,000 B.Th.U. per lb., which is a lower price than it is at present. Under these conditions the 3d. per passenger train-mile is justified.

Mr. Vesey Brown also referred to the dual classification of passenger traffic already dealt with, and deprecated anything but the frank acceptance by the railways of the tramway and motor omnibus competition. As he himself points out, however, it is a condition governing electrification. If a particular form of competition which the railway, as (in general) the largest ratepayer in any parish,

* F. LYDALL. Electric locomotives. *Journal I.E.E.*, vol. 51, pp. 748–50, 1913.

Mr. Smith. may be called upon to support through the rates, makes a frequent stopping service unremunerative it may be best for the railway not to cater for it at all.

Mr. Hawthorne has admirably reviewed the various kinds of suburban service, and in general it is only class three, extending from about 16 miles outwards, which is profitable provided the train density is high. With electric traction it is possible to determine the minimum train density which will pay with a given schedule of fares. If fares are, however, continually lowered to meet competition, the margin is so extremely small that an electrification which promised well may turn out a failure. The fares charged are really the governing factor.

Mr. Hawthorne's argument that railway electrification would naturally develop along the present lines of suburban working extended to inter-urban working, supplemented and amplified the remarks on the same lines by Mr Vesey Brown and Mr. Redman. His argument is supported by his classification of suburban traffic already referred to, and in the busy industrial centres of the Midlands, the North, and the North-East of England, it appears almost self-evident, though the idea is new to the author. The problem of running inter-urban services on the same tracks as a dense suburban traffic is, as Mr. Hawthorne points out, very difficult of solution. The author is glad to be corrected as to the electric train density on the North-Eastern Railway, and entirely agrees with Mr. Hawthorne's insistence that there are many ways besides reducing the cost of electricity in which the total cost of power may be reduced. Regeneration, advocated in the discussions at London and at Birmingham, is a fascinating, if somewhat elusive, problem, and the keeping down of weight is fully treated in Mr. O'Brien's paper on Electric Rolling Stock.*

Mr. Prescott's contribution to the subject of electric braking as apart from regeneration, and his clear statement of the way in which it may be used to improve the headway in very dense urban and suburban traffic, is important, and supplements Mr. Mordey's remarks on the same subject in London.

The author is entirely in sympathy with Mr. Hunter's clear statement of the incidental advantages of electric traction to which no money value can be attached in an estimate, but which may be real railway economies at the same time that they are improvements from the point of view of the public. His instance of the saving in painting of that part of Newcastle Central Station devoted to electric rolling stock is an excellent example. All that he says about the flexibility of the multiple-unit motor-coach train from the traffic point of view, the working of a goods service electrically, and the improvement in the series motor characteristic, especially with the object of reducing the ratio of the maximum to the average speed, is very much to the point. The use of the Ward Leonard system for goods working is dealt with in Mr. Lydall's paper, and needs to be carefully worked out and if possible tried experimentally in England as it has been on the Paris Metropolitan Railway. It is agreed that there should be uniformity in the unit used for acceleration. Miles per hour per second for railway purposes is the most rational, but unfortunately it is not suitable for the many other applications of the electric motor to electrically-driven Mr. Smith machinery used by railways, such as cranes, lifts, traversers, and winding or hauling gear.

Mr. Beard touched on several of the difficulties in presenting an estimate of railway electrification, which should take into account future as well as present conditions, owing to the continual increase in operating charges. The author believes Mr. Beard is quite right in considering that, as time goes on, electrical operating charges will tend to decrease while steam operating charges will tend to increase; but it is not the electrical engineer who takes the risk of an electrification scheme, and only time can convince the management of this tendency. The author has not exactly charged the whole capital cost of track equipment, sub-stations, and distribution against the fast passenger service, but he has shown (assuming his figures are accepted) that a sum would be available to meet these charges which would probably not come within 50 per cent of their cost under present conditions, whatever system is used.

(*Communicated*): The author wishes to associate himself with all that Mr. Marshall has said on his behalf in reply to the discussion at Middlesbrough. One or two supplementary remarks may, however, be of interest.

With regard to adhesion it is to be remembered that the maximum draw-bar pull of a locomotive is in general required at starting, and especially when starting on a grade. The uniformity of the torque of an electric motor, as compared with that of a reciprocating engine, only holds true when the speed is not being increased by some such device as the controller universally used with the continuous-current motor and generally used with the alternating-current motor. The fluctuations of torque when notching an electric locomotive are fully treated by Mr. Lydall in his recent paper.* In the reciprocating steam locomotive fluctuations have been reduced by design, as they can be in the electric locomotive, but in the latter they only exist during the starting period, and cease after the motor is working with full electrical pressure on its terminals. It is, however, during the period of uniform acceleration that fluctuations in torque are undesirable. Mr. Brettelle refers to the Lancashire & Yorkshire Railway electrification between Bury and Holcombe Brook. The motors are series motors used in pairs across the 3,500-volt continuous-current supply so that there is a pressure of 1,750 volts across each motor. For control, lighting, heating, and brake pump a motor-generator giving 100 volts is necessary, and this necessity led to the suggestion of increasing the size of the motor-generator and using it also for the field current. With regard to this speaker's comment on the price of coal, the figures were based on coal at 12s. 6d. per ton, or 9s. per ton for coal of 10,000 B.Th.U. per lb. There were not two prices.

It is satisfactory that engineers should recognize the inflexibility of the electric locomotive, when equipped with motors having a series characteristic, as compared with the steam locomotive *quâ* speed. It is important that all possible means of improvement in this direction, as also in the direction of obtaining controlled regeneration, should be carefully studied by all interested in electric traction.

* H. E. O'BRIEN. The design of rolling stock for electric railways. *Journal I.E.E.*, vol. 52, p. 455, 1914.

* F. LYDALL. Motor and control equipments for electric locomotives. *Journal I.E.E.*, vol. 52, pp. 387–91, 1914.

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THE SIGNALLING OF A RAPID-TRANSIT RAILWAY.

A STUDY OF THE RELATION BETWEEN SIGNAL LOCATIONS AND HEADWAY.

By H. G. Brown, Member.

(*Paper received 12th March, and read before* The Institution *2nd April*, 1914.)

The maximum headway which it is possible to obtain is primarily determined by the acceleration and deceleration rates and the maximum speed of the rolling stock, and the length (in time) of the station stops. The result is to a certain extent influenced by the geographical lay-out of the line, and also by the character of the limitations imposed by the signalling system which must necessarily be installed for the purpose of creating safe conditions of operation.

The train characteristics and the geographical lay-out of the line are generally determined before the question of signalling is considered. The length of time required for station stops can be estimated with a certain amount of accuracy, but still remains a variable quantity.

With any of the present systems of signalling it is necessary to divide the line into signal sections, a signal being provided at the entrance of each section for the purpose of indicating the condition of the section, *i.e.* whether occupied or unoccupied.

There are a number of methods of operating and controlling these signals. For instance, they may be controlled manually or automatically. The lock-and-block might be mentioned as a most effective method of manual control, the track-circuit system being the most reliable method of obtaining automatic control.

An automatic system can be arranged to allow of a far greater number of trains being operated than with any system of manual block signalling that affords an equivalent degree of safety.

The apparatus of an automatic system operates practically instantaneously, while with the manually-operated system time is required for the performance of the manual operations, and if the system is designed to obtain a high degree of safety a number of manual operations are usually required to be performed in a definite sequence. The time required for manual operation cannot be reduced when the section is shortened. For example, consider a section having a certain length. The length of this section, expressed in time, is equal to the time required by the train in running through the section. It is evident that if the section is shortened by subdivision a point is reached when the time required for the manual operation of the block system is nearly equal to that required by the train to run through the section; and should the section be made still shorter it will be found that the train is delayed by the signal system, and that the capacity of the line is being reduced instead of increased.

It has often been claimed that but little time is required for the manual control of a block system; but if these claims are investigated one or more of the following conditions will be found to exist.

Safety has been sacrificed to obtain speed in operation; or a record time has been quoted instead of the average time required by the average man working at a speed that can be maintained without undue strain throughout the time that he is on duty; or the system is practically a form of automatic system requiring a limited amount of manual control. It therefore cannot give the full advantages of the purely automatic system, and is more expensive to operate than either the automatic or the manual considered alone. Under conditions that require a frequent train service it will be found that an automatic system is the cheapest per unit section.

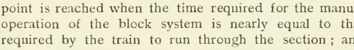


Fig. 1.

On rapid-transit lines that are equipped with an installation of automatic signals it is customary to provide train stops, which are located at the signals. These train stops assume an operative position when the signal is at danger, and should a train run past a danger signal they co-act with the brake mechanism, causing an emergency application of the brakes, the train being stopped thereby.

Fig. 1 illustrates one arrangement of automatic sections. Signal 1 assumes the danger position when the front end

of the train enters section A, and remains at danger until the rear end of the train has passed out of the section. Section A controls signal 1, section B signal 2, section C signal 3, and so on. It will be noted that these sections overlap the signals in advance. This results in signal 1 not assuming the clear position until the rear of the train has passed signal 2 by a pre-determined distance. A train passing a signal at danger at its maximum speed has its brakes applied by the train stop and is thereby brought to a stand before it has travelled far enough to collide with a preceding train. The length of this overlap is influenced by alignment and grade, and is usually nearly double the length required for an emergency deceleration from maximum speed. This extra allowance required for the stop, the average speed when the train is moving is lower than it is between stations, as the station section includes both a deceleration and an acceleration. When providing signalling arrangements for a short train interval, it will be found that the station sections are the ones most difficult of arrangement.

Fig. 2 is a train diagram showing the maximum headway through an ordinary station, and is based on the following data:—

Maximum speed of trains: 25 miles per hour.
Acceleration: 1 mile per hour per second.
Service deceleration: 1·8 miles per hour per second.
Length of train: 300 ft.

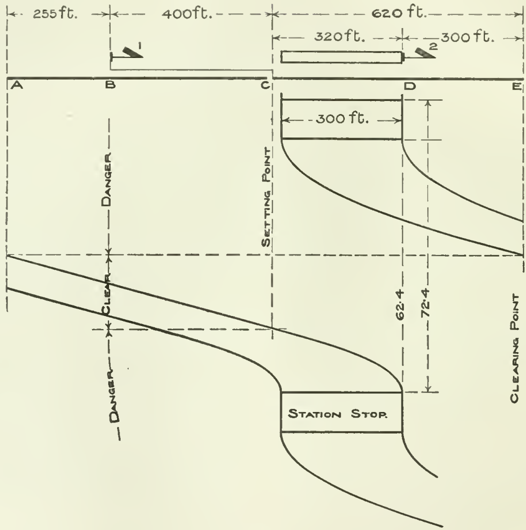


Fig. 2.

is necessary because of the possibility of the deceleration rate being less than is considered normal, due to imperfect brake adjustment or greasy condition of the rails.

The time interval between trains being the important factor, the length of sections is considered in terms of time instead of distance; and it is obvious that the section in which a station is included may, on account of the station stop, be a longer section in time than a section between stations that is many times its length lineally, because between stations it can be assumed that the train is travelling at its maximum speed. The time occupied in a station section is long because, in addition to the time

Signal 1 is controlled by the section C E, and is usually called the home signal. The overlap B C is 400 ft. long. The overlap between D and E is 300 ft. long. The length of this overlap has been reduced by 100 ft. because the section beyond E—being the starting section—is a relatively long one, and it can be assumed that a train stopping in this section would stop at the next signal. The distance A B is what may be termed the sighting distance.

With a deceleration rate of 1·8 miles per hour per second, if a train is travelling at the maximum speed of 25 miles per hour it would be necessary to apply the brakes at a

point 255 ft. in front of signal 1 in order to enable the train to be stopped at the signal.

The minimum interval between trains is determined by the time elapsing from the moment that the front end of the train passes A until the moment that the rear end passes E, and, as shown, this time equals 62·4 seconds plus the time elapsing while the train is standing in the station. Assuming a 10-second stop, the maximum headway possible would be 72·4 seconds. Should the station stop of the first train equal 21 seconds instead of 10, signal 1 would move to the clear position 11 seconds later than the time shown on the diagram. The brakes must be applied on the second train when its front end passes A. The 11-second signal delay plus a 3-second reflex of the driver and train mechanism approximates the 13·9 seconds required for a complete deceleration, therefore the 11-second signal delay results in a full deceleration instantly followed by acceleration. The distance A D is sufficient for a complete acceleration and two decelerations between zero and a speed of 25 miles per hour. From the point A there is a deceleration from 25 miles per hour and an acceleration to 25 miles per hour in a distance of 713 ft., and the delay to the train can be obtained by a comparison of the time required to decelerate and accelerate with the time occupied in running the 713 ft. at 25 miles per hour.

This comparison is shown in Fig. 3. A is the sighting distance, 255 ft. in the rear of the signal. The preceding train has been delayed 11 seconds, the signal clearing 3 seconds before the following train comes to rest at B.

A 3-second reflex interval is shown, after which acceleration commences. If the train had continued at the speed of 25 miles per hour it would have travelled the 713 ft. in

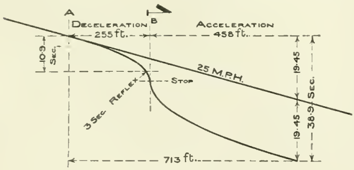


Fig. 3.

19·45 seconds. The fact that the signal cleared 11 seconds late results in a delay of 19·45 seconds, as shown. This is evident from the fact that the second train has an average speed of 12·5 miles per hour.

In Fig. 4 the horizontal dimensions represent delay of the first train at the station in seconds. The vertical dimensions represent the resultant delay to the second train, the curve C being the curve of equal delay. The curve A represents the theoretical delay of the second train.

Up to a certain point it will be noted that the resultant delay is less than the original delay. Beyond that point the resultant delay is greater than the original delay. Curve A is a theoretical curve which makes no allowance for the reflex of the driver.

The reflex of 3 seconds referred to may be explained as follows. A train is approaching a signal at danger and is decelerating. Before the signal is reached the latter moves to the clear position; the deceleration will then continue for 3 seconds beyond the moment at which the signal cleared, this 3 seconds being the time required by the man and apparatus to initiate the acceleration. The 3-second value is an arbitrary assumption. Curve B shows the resultant delay to the second train with allowance for the 3-second reflex. It will be seen that the resultant delay under all conditions is greater than the original delay, and from zero grows greater until a certain point is

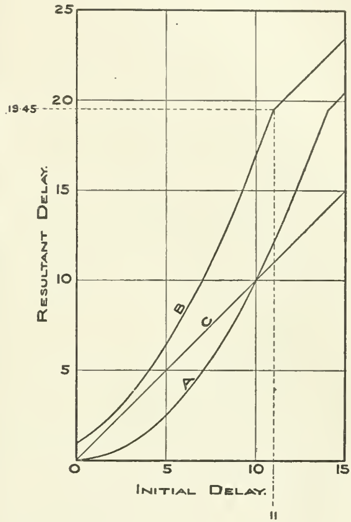


Fig. 4.

reached, beyond which the curve B is parallel to the curve C. Under the conditions considered, this parallelism commences at an original delay of 11 seconds, and from there onwards the resultant delay is 8·45 seconds greater than the original delay.

This parallelism between curves C and B commences when the initial delay plus the reflex equals the time required for a complete deceleration. It is evident that for every additional second of initial delay the train waits the equivalent time at the signal. If the previous sections are equal in time to the station section, the delay is quickly felt by all trains in the rear. The delay to the following trains is accumulative. The initial delay, we will assume, is 11 seconds. The second train is delayed 19·45 seconds, the third train 27·9 seconds, and so on, the third train starting from the station 27·9 seconds later than its schedule time.

It will be seen from the above that the interval shown in Fig. 2 as 72·4 seconds is increased to 80·95 seconds, and, provided that each train stops at the station for 10 seconds, the original delay of 11 seconds has the effect of increasing the interval as stated. The tenth train will be nine times 8·45 plus 11 seconds later than its schedule time when passing the station at which the original delay occurred.

It has been assumed that the second and third trains stop at the station for the standard time. It will be evident, however, that this is unlikely. The normal time between

If 10 seconds is the usual station stop, the second train will require more than a proportional additional time, because the time required to load people is not directly proportional to the number to be loaded. This is due to the choking of the means of ingress and the tendency of passengers to move more slowly the moment that they are actually on the train, also to platform congestion. It is fair to assume then that the third train will be much more behind its schedule time than the 27·9 seconds stated.

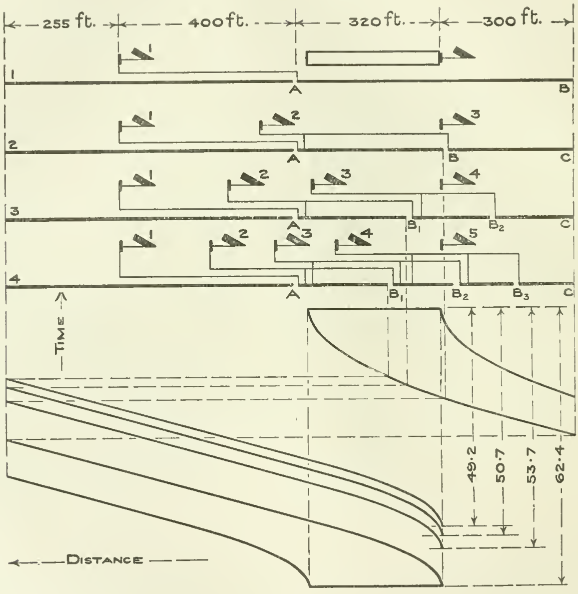


Fig. 5.

the departure and arrival of trains is 62·4 seconds. The second train arrives 71 seconds after the first train has left, and therefore finds more than the usual number of people on the platform. The interval between the starting of the second train and the arrival of the third train is also 71 seconds, and the third train in turn finds a proportionately greater number of people at the station who require accommodation.

Assuming that the volume of the flow of people on to the station platform is continuous, it is evident that each following train must accommodate more than its usual number of passengers.

The foregoing proves that the interval of 72·4 seconds with a 10-second stop is the theoretical minimum, as stated, but this interval cannot be satisfactorily operated, due to the possibility of the station stop exceeding the 10 seconds allotted. The headway which can be practically maintained is therefore equal to 62·4 seconds plus the maximum length of station stop; and any stop longer than what has been, by observation, arbitrarily determined as the maximum, must of necessity result in disorganization of traffic.

The minimum train interval which is practicable with the signalling arrangements illustrated would probably not

be less than double the theoretical minimum interval shown in Fig. 2.

Let us assume that a service is being operated with an interval of double the theoretical minimum. Each minor delay that occurs has a tendency to cause the trains to bunch. Eventually a point is reached when the trains are running as near the real minimum interval as possible, and then any further delay results in accumulative delay with its attendant disorganization, and such disorganization is generally found to continue until the cessation of traffic after midnight.

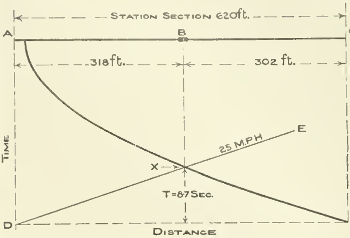
It is evident that the station section is the critical one from the standpoint of time, and if a more frequent service is required the signalling arrangements at the station must be modified. The first step would be to provide one inner home signal, and it is possible that it may be considered advisable to install two or three inner home signals.

Fig. 5 shows the decrease in the train interval obtained by an increase in the number of home signals. Line 1 has the same signal arrangements as illustrated in Fig. 2. Line 2 has an additional home signal, necessitating the subdivision of the station section A C at the point B. No. 1 is controlled by the section A B, and No. 2 by the section A C. In line 3, signal 1 is controlled by the section A B_1, signal 2 by the section A B_2, and signal 3 by the section B_1 C, signal 3 being located on the rear end of the station platform. In line 4, signal 4 is located on the platform. This location has the disadvantage that the front car of a train stopping at this signal would be at the platform. In the majority of cases the advantage obtained by the four home signals would hardly justify the cost of the complete extra section, the saving in time being only 1½ seconds. The arrangement shown on line 3 would have a decided advantage over line 1, and the additional saving of 3 seconds to that shown in line 2 is well worth while in the majority of cases. The sighting distance for signals has been assumed as 255 ft. It is evident that the distance between signals 1 and 2 is the same as the distance between the sighting points of these signals. The following train, travelling at 25 miles per hour, should require the same time between these sighting points as is required by the tail of the preceding train to travel between the points B and C, and it is evident that the distance B C must be equal in time to the distance between signals 1 and 2. A 400-ft. overlap is allowed between signal 2 and B. Therefore, the distance from signal 1 to signal 2 is the same as the distance A B, and at 25 miles per hour is equal in time to the latter part of the acceleration occurring between the points B and C. The same time and distance relations exist in lines 2, 3, and 4, of Fig. 5. Take line 4 as an illustration. From 1 to 2 is equal in time to B_1 to B_2, and equal in distance to A to B_1. From 2 to 3 is equal in time to B_2 to B_3, and equal in distance to B_1 to B_2. From 3 to 4 is equal in time to B_3 to C, and equal in distance to B_2 to B_3.

Fig. 6 shows the method of ascertaining the location of the point B. The line D E is drawn at an inclination equal to 25 miles per hour, and the point where it intersects the acceleration curve gives the correct position to subdivide the section A C.

The method of dividing the distance A C into 3 sections is shown in Fig. 7, and differs slightly from that shown in Fig. 6.

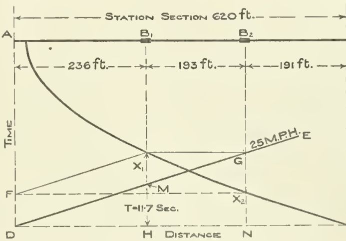
The 25-mile-per-hour line D E occurs in Figs. 6, 7, and 8. A trial line X_1 G is drawn first, then the vertical



Two Home Signals.

Fig. 6

ordinate G N is drawn. This line intersects the acceleration curve at X_2. The point F is found by drawing a line



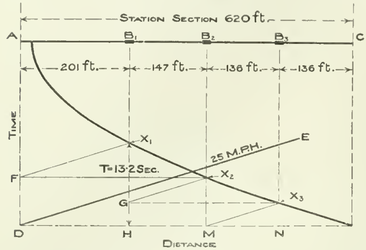
Three Home Signals.

Fig. 7.

from X_2 parallel with N D. A line connecting F with X_1 should be parallel to the line D E.

Fig. 8 shows the division of the station section A C into four sub-sections. Select an approximate position for the point X_2 a little more than half-way between A and C. Draw the horizontal line X_2 F, and a line from F parallel to the line D E, to intersect the acceleration curve at X_1. Next, draw the ordinate X_1 H. This ordinate gives the position of the point B_1. Draw the line X_2 G parallel to the line D E, then a horizontal line from G to X_3, also the ordinate from X_2 to M. A line connecting X_3 to M should be parallel to the line D E if the trial position of X_2 was correct. If this result is not obtained, the inclination of the line X_3 M will suggest a new trial position for X_2. It will be evident that three comparisons between the average speed during acceleration in the separate sections and a maximum speed of 25 miles per hour are shown; the first comparison X_1 to F against X_1 to X_2; the second comparison X_2 to G against X_2 to X_3; and the third comparison X_3 to M against X_3 to the ordinate C. It is evident from the construction that the time of the preceding train in one

section is equal to that of the following train travelling at a speed of 25 miles per hour through a distance equal to the length of the preceding section. These points of subdivision can of course be calculated, but the graphic method shown is simpler and requires much less time.



FOUR HOME SIGNALS.

FIG. 8.

Also there is less liability of mistake, as an error is immediately evident. The acceleration and deceleration curves used in these diagrams have been calculated from the rates stated, and it has been assumed that trains would approach the outer home signal at maximum speed. It is most probable in practice that the average acceleration or deceleration would differ from the theoretical curves shown, and it is unlikely that the trains would approach the outer home signal at maximum speed, as in all probability they would be coasting at this point.

In actual practice, it would be found advisable to provide for a signal sighting distance of at least 500 ft.; but as 255 ft. is the deceleration distance from 25 miles per hour at the rate stated, this distance has been assumed as the sighting distance for signals, because any distance additional to the deceleration distance is required by the personal equation of the driver, and if considered herein would introduce a variable factor which would confuse the explanation of the principles involved. When locating a number of inner home signals at any particular station, it is necessary definitely to determine the conditions which exist. Speed curves should be obtained from an average of many tests of accelerations and decelerations at the station concerned; also the average speed in the vicinity of the home signals should be found. These factors are influenced by alignment and grade and other local conditions of service, as well as by the driver's habitual method of acceleration and brake application. When tests of this kind are made at any definite locality it is surprising how near to the average are the majority of the accelerations and decelerations, a small percentage only having any radical variation.

The time required for the station stops is the most important of the various factors which influence the time interval, and while the value of this factor is mainly dependent on the amount of traffic at the station considered, it is greatly influenced by the physical arrangement of the station, and also by the efficiency of the train and platform staff.

If it is wished still further to increase the service, there is another arrangement of station signalling which is considered very satisfactory where it has been installed, and which undoubtedly further reduces the time elapsing between the starting of the first train and the arrival of the next. With the speed-control system the second train is allowed to decelerate to a position very near the rear end of the train standing in the station, while in all the signal arrangements described a 400-ft. overlap has been provided. In the previous arrangements, should the train remain in the station more than the usual time, the following train would be stopped at the outer home signal, and when the signal cleared would accelerate and then decelerate to the stopping-point in the station. With the speed-control system, as the following train would be stopped only a short distance in the rear of the train standing in the station, it has much less distance to travel than in the former case. The important function of the system is its control of the deceleration of the following train. This result is obtained by dividing into a number of signal sections the distance between the outer home signal and the point at which the train is intended to stop, a train stop and signal being provided at each point of subdivision. A timing apparatus is installed in connection with each signal and train stop, and is arranged so that the signal clears a predetermined number of seconds after the entrance of the train into its approach section. The time interval between the entrance of the train into each section and the clearing of the signal at the entrance to the next, is based upon the portion of the deceleration curve which should occur within the section, with the result that a train approaching an occupied station and decelerating properly finds that each signal clears just before it is reached, but if it fails to decelerate at a sufficiently rapid rate the brakes are applied by the next train stop because it has travelled through the approach section in too short a time. The speed-control system as described has the drawback that the deceleration of the train is checked only at certain points. It is possible to enter a section at a speed below normal and then to accelerate, passing the next signal after it had cleared and then being tripped by the following signal, by that time having attained a higher speed than was anticipated at that point. An arrangement of sections and section times which would satisfactorily overcome this liability would partially defeat its own purpose.

A system of this type is a check on a driver who has failed to decelerate sufficiently quickly through error rather than intention, and it cannot provide for extreme negligence or ill-intention.

The advisability of installing speed-control at junctions and on steep inclines has been suggested, but the author would hesitate to make such an application of the system, at least of the form in which it is now in use. To get sufficient control of the train, the sections must be very short, and as the reflex time of the apparatus is not always perfectly constant any variation would quickly assume a larger percentage of the total time allotted to any section.

The advisability of the use of the speed-control system as at present installed is open to argument, and the author is of the opinion that in the majority of instances it is better to maintain at all times a definite minimum distance between trains.

Discussion.

Smith. Mr. Roger T. Smith: With regard to the general subject of signalling as it affects electric traction, I think there are two types of signalling likely to be rapidly developed: first, track circuiting for signalling purposes, in which the train itself completes the circuit and through a relay can work the signal; and secondly, cab signalling on locomotives. The paper deals only with the results of track signalling in a particular case, no reference being made to principles or methods of application; but I think we ought to remember that as far as electric traction is concerned the signal engineer and the traction engineer have to make use of the same rails, and they do that for their mutual advantage. The maximum number of trains per hour during the times of busiest traffic can only be obtained by the co-operation of the traction engineer and the signal engineer, and both deserve about equal credit for the results achieved. Most track circuiting on large railways is at the present time carried out by continuous current at very low voltages—rarely exceeding 2 volts—and such currents are of course subject to interference by any stray earth current. There comes a time in most busy places, especially where there is any electric traction by continuous current on the railway itself, or where there are electric tramways in the neighbourhood, or even possibly where a power or lighting supply can go to earth, when the risk of interference to track circuits from stray currents is a greater risk than the signalling engineer can afford to take. In such places alternating-current track circuiting may be said to be the complete solution of this dual use of the same rails by the traction engineer and the signal engineer. The alternating current for track circuits can quite easily be superimposed on continuous current in the same rail. It can also be superimposed on other alternating-current traction currents in the same rail, provided the periodicity of the former is two or three times as great as that of the latter. Impedance bonds at the end of the signal section choke back the track-circuiting currents while allowing the traction currents to pass. I think it is important, in the case of any railway which has in contemplation the use of electric traction in any form, that the signalling engineer and the traction engineer should get together and determine from the start the exact terms on which they are both going to make use of the same rails. Fig. 2 in the paper shows a service with a normal time interval of $62\frac{1}{2}$ seconds; that means 57 trains per hour each way. The author, however, on page 548 says that with the type of signalling shown in Fig. 2 double this interval would probably be wanted in practice, that is, it would only be possible to get 29 trains per hour each way as a maximum train service. Now at the present time on the London underground railways 44 trains per hour are, I believe, actually being run, and 50 trains per hour each way as a maximum during the "rush hours" has been stated to be possible. I should like to ask whether lines 2 and 3 on Fig. 5 represent anything like 50 trains per hour each way, not in theory, but in practice, and whether that is the type of signalling that the author would propose for such a number of trains. I think the case may perhaps be stated somewhat differently from the way in which it has been put in the paper. If 50 trains per hour each way are being run, the time interval is approximately 72 seconds, and from the last home signal into the station will, with the speed and retardation mentioned, probably take 35 seconds. To accelerate out of the station and to leave it will take another 10 seconds, and we have thus accounted for 45 seconds out of the 72. There remain 27 seconds for the station stop and for any margin. Provided the station stop never exceeds 27 seconds it appears as if under those conditions, with the accelerations and decelerations mentioned in the paper, 50 trains per hour could be run each way. I should like to ask the author whether he considers that limit has ever been reached in actual service, or if not, whether it could be reached. Mr. Smith.

Mr. A. T. Blackall: I agree with the author that an automatic system of signalling will allow of a far greater number of trains being operated than any manual system which would be equally safe. The graphic method which has been devised by the author for determining the locations of signals and the dividing points of the sections should prove very useful to engineers and others who have to provide for the signalling of a rapid-transit railway. I take it that the author's experience of rapid-transit railways has mainly been gained on underground lines, and in some respects the conditions underground will probably vary from those on a surface railway. The Great Western Railway Company is considering at the present time the problem of signalling in the case of an electric rapid-transit surface railway. An automatic system has been proposed which differs in certain respects from the usual automatic system of signalling employed on the existing rapid-transit railways in London. In order to provide for the ready sighting of the signals above ground, particularly in snowstorms, fogs, and bad weather generally, it is proposed to have signals of a very distinctive type. It is suggested that these signals should be what is known as "upper quadrant" signals, that is to say the arm of the signal when not in the "stop" position will rise above the horizontal instead of dropping below it, as in the case of the ordinary signals used on most railways. If the proposed signals are adopted they will be known as three-position signals, having what I believe American engineers call three "aspects." The first aspect, or the third—it does not matter much which—is "Stop," and the arm stands out at right angles to the post. A red light is shown at night. The second aspect has the arm raised 45 degrees, which means "Proceed Cautiously" (yellow light at night), and the third aspect has the arm pointing upright, which means "Proceed" (green light at night). These signals will be controlled by alternating-current track circuits. When the "Stop" aspect is exhibited, what is meant is that the section immediately in front of the signal is blocked. When the "Proceed Cautiously" aspect is exhibited, it means that the section next beyond that is blocked. Whilst when the "Proceed" aspect is exhibited it means that neither of those sections is blocked. In addition to those 3-position signals it is suggested that an automatic system of cab signalling should be provided, in conjunction with the usual train stops, the signals in the cab to be given by Mr. Blackall.

Mr. Blackall. means of the passage of shoes upon the trains over ramps fixed between or by the side of the running rails, so as to provide for the contingency of drivers failing to observe the visual signals displayed at the side of the line. It is thought that such an arrangement will be particularly useful, and much facilitate the working of traffic in times of fog and in bad weather. It is probable that the arrangements which I have mentioned will have to be supplemented by the use of treadles for placing the signals to danger and clearing them, since it appears doubtful whether under some conditions an alternating-current track-circuit will take care of light engines of the ordinary locomotive type which may possibly run over the line, and light-weight trains composed of empty goods trucks. It seems probable, particularly after the line may have been closed for a few hours, that the alternating-current track-circuit arrangement might not in such cases do its work properly. This seems to make it necessary, in addition to the apparently complete arrangement which I have just mentioned, to provide treadles. I should like to ask the author whether in fixing the location of signals and the dividing points of sections he actually adopts in practice the diagrammatic method which he has explained.

Mr. Firth. Mr. H. W. FIRTH: Mr. Blackall has drawn attention to one point which I think is important, namely, that the strict title of the paper should be carefully kept in mind, viz. a system or method of signalling for rapid-transit lines, and it must not be assumed, as Mr. Blackall has pointed out, that this is universally suitable for lines carrying general traffic. I regret that the author has not given us any information whatever upon the subject of signalling at junctions or terminals. He rightly emphasizes the importance of the length of station stop in rapid transit, but the junction and the terminal factors are in some cases of almost equal importance, and apart from the traffic point of view the technical aspect of the signalling problems in junctions and terminals is extremely interesting. I should very much have liked the author to have given us his views on these uses of electric signalling, and as to how far such automatic signalling will decrease the limitations of those junctions and terminals. I think it is all the more important too because my opinion is that these are just the particular cases where automatic track circuiting does score heavily over manual arrangements. On the plain, straight-through runs with the lock and block arrangement manual operation can and does in practice give surprisingly quick and good results. On the other hand, in heavy, quick traffic over junctions, and in traffic such as that on the Metropolitan District Railway or on the Tubes, I think it is quite safe to say that that type of traffic could not be handled except under automatic track-circuit-signalling conditions. The length of station stop, which the author emphasizes, is, as I have said, of great importance. He points out at the bottom of page 550 the various factors which influence the time interval. One point, which I think he has not mentioned, and which in my opinion is very important, is the influence of train design upon the time of the station stop. I have timed several hundred station stops on London railways, both steam and electric, and I am certain from my observations that the type of rolling stock, the arrangement of doors, and so forth, are of great importance in determining the length of the station stop. The author has to some extent cleared up one point which I was going Mr. Firth. to mention about the overlap of 300 ft. shown in Fig. 2 from D to E. As he has mentioned, with a train not calling at that station that overlap is certainly not enough, but he seems to have based his time calculations entirely on the assumption that the trains call at all stations. I should like to know how the elimination of a certain number of station stops over a given line will affect the signalling and the total carrying capacity of the line. I was very much interested in the author's remarks as to time-discriminating signals. He does not seem to be very enthusiastic about them. In *Elektrische Kraftbetriebe und Bahnen* * last year there was a paper by Brugsch and Briske in which a very exhaustive account was given of an investigation into the traffic capacity of a rapid-transit line, and in that paper the use of these time-discriminating devices was mentioned as being quite a usual practicable arrangement; in fact, I think it was said that satisfactory methods of carrying this out were numerous and need not therefore be referred to. I believe the method was first suggested by Mr. Bion J. Arnold in his Report on increasing the traffic capacity of the subway in New York, and I believe it has been in operation there. I should be very interested if the author could tell us where this time-discriminating arrangement is in operation, and what success has been obtained with it. Another question that I should like to ask is this: the paper is apparently based on a 300-ft. length of train; assuming that a line is laid out with the signalling as described by the author on a basis of a 300-ft. train, what will be the effect upon a signal lay-out of increasing the train length to say 400 ft. if the necessities of the traffic demand that length of train being used? That is to say, what differences would the author make in the signalling in the first instance when considering a line where 300-ft. trains are required at very short intervals, to allow for the possible increase in the length of trains?

Mr. H. G. BROWN (*in reply*): Mr. Smith has raised the Mr. Brown. question of the number of trains per hour shown in Fig. 2, and wishes me to state the results in trains per hour with the different arrangements of signalling shown in Fig. 5, lines 2, 3, and 4, and so forth. In replying to that I will answer to a certain extent one of Mr. Firth's questions. I was anxious to explain the principle of cumulative delay, and had therefore made certain definite assumptions, so that in all instances the results would be directly comparable. Referring to Fig. 2, take a railway with a number of stations, some busy, some not busy. It is quite possible that a satisfactory service could be operated with a headway less than double the time shown in the diagram, provided that the critical stations were not too great in number; in fact, it is done on the District Railway at the present moment and on some of the Tubes. Supposing that every station were a critical station, then I doubt very much if a continuous schedule, day in and day out, could be operated if the headway were much less than double the theoretical minimum, but it is quite possible to operate a service with a few critical stations when those stations come within 10 or 15 per cent of the theoretical. Fig. 5, line No. 2, represents practically 55 trains per hour; line No. 1 represents 50 trains per hour; and line No. 3 represents 59 trains per hour, that is, assuming a 10-second stop. It is very difficult to say exactly what schedule

* Vol. 11, p. 553, 1913.

Mr. Brown. could be run with the signalling installation shown, because, as I say, it depends so much on what is occurring in the other parts of the line—how many narrow necks the bottle has. I think they maintain the 44 trains per hour in the "rush hour" with more or less success on the District Railway at the present moment, and I think the maximum number of inner "homes" at any one place is two, which corresponds to line No. 3. A schedule of 44 trains per hour is not readily maintained; it is a strenuous proposition, and every additional train makes the fight infinitely harder, much more so than is apparent.

Mr. Blackall referred to two things, namely, cab signals and whether I myself make use of these diagrams. I am strongly in favour of cab signals for the purposes for which they were meant. I think that on the Great Western Railway they have the proper idea of the use of the cab signal. As to whether I use these diagrams, I may say that I do not always have time. There is some difficulty in finding out the conditions that actually exist at any given place, and a great deal more judgment than mathematics is required.

Mr. Firth referred to the question of junctions and terminals. I intentionally avoided that, because I did not want to make the discussion too long. The junction and terminal proposition from the signalling standpoint is, if I may say so, more interesting, inasmuch as it is more complicated than the simple illustrations given. A terminal gets more complicated when one tries to lay out and demonstrate definitely what occurs, because as soon as a terminal is approached one also encounters a hundred questions which cannot be calculated and which must be assumed arbitrarily—and the correctness of the assumptions depends upon the judgment and the experience of the person making them. I knew that if I referred to a junction, or showed a train diagram of a junction, or tried to justify the location of signals, or the length of track circuits at a junction, it would start a discussion which would take too much time. The physical arrangement of the station has a very great effect on the possible headway. There is one thing that has always surprised me greatly, namely, that so many people know how to arrange a station perfectly, and so few stations are arranged perfectly. The two things do not seem to justify each other. There are some fundamental principles to be borne in mind. One might be said to be the fact that opposing streams of people should be kept separate, so that the progress of people, either going to or leaving trains, will not be impeded. The same principle applies in reference to car design. I am very strongly of opinion that it is better to have all the people moving in one direction inside a carriage standing in a station, that is, in at the middle and out at the ends when there are three doors, or vice-versa; or in at one end and out at the other with two doors only, the two ends of the carriages which are together having the people either coming out or going in. That experiment was tried on the District Railway some years ago when the line was first electrified, and for some reason it was given up. I think it was a great mistake, because I have great faith in the capacity of the public for training of that kind. Mr. Brown.

In reference to the 300-ft. overlap at starting signals, many of the overlaps are short on the District Railway, and on similar railways where all trains stop at all stations. The Board of Trade allows a very short starting-signal overlap here in London, say 15 or 20 ft., but it requires a longer overlap when trains run express through stations. I think one thing has to be borne in mind when considering station overlaps, etc., namely, that it is as necessary to allow the traffic to run as it is to protect it, because it is impossible to do the latter until the former occurs. We find it necessary to obtain dispensations from the authorities in the case of a number of things in railway work, otherwise it would be impossible to operate railways. Certain conditions may justify the modification of general principles.

The speed control, as Mr. Firth points out, was first installed on the Interborough Rapid Transit line in New York. The idea of a system of speed control is excellent, and would be exceedingly useful if the method were satisfactory in detail. In my opinion the system as installed is, however, not sufficiently good to warrant its installation under conditions where it would be of most use.

The effect on the interval, of trains longer than those shown in the diagram, has been referred to. The use of longer trains would undoubtedly increase the time interval, while shorter trains would to a certain extent decrease the interval. The signalling would of course be arranged to accommodate the longest trains in general use. There is greater disadvantage in running trains longer than those that the signalling is planned to accommodate than would result if shorter trains were used; the signalling arrangements would therefore be planned to accommodate the longest trains. With trains shorter than those shown, the following train would find the outer "home" clear, although a train was standing at the starting signal, and it would be able to run up to the first inner "home." This would be perfectly safe, as all the home signal overlaps are full length.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF THE 19TH MARCH, 1914.

Proceedings of the 565th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 19th March, 1914—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 12th March, 1914, were taken as read, and confirmed.

The subject of "Electric Battery Vehicles" was discussed (see page 493), and the meeting adjourned at 9.55 p.m.

ORDINARY MEETING OF THE 26TH MARCH, 1914.

Proceedings of the 566th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 26th March, 1914—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 19th March, 1914, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

Donations to the *Library* were announced as having been received from A. Blok, W. Brew, A. E. Kennelly, and Messrs. Siemens Brothers & Co., Ltd.

A paper by Messrs. K. M. Faye-Hansen, Associate Member, and J. S. Peck, Member, entitled "Current-Limiting Reactances on Large Power Systems" (see page 511), was read and discussed, and the meeting adjourned at 9.50 p.m.

ORDINARY MEETING OF THE 2ND APRIL, 1914.

Proceedings of the 567th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 2nd April, 1914—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 26th March, 1914, were taken as read, and confirmed.

Messrs. W. R. Mickelwright and M. G. Tweedie were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Members.

de Valbreuze, Robert.
Michôd, Percy Douglas.
Powell, Alfred Everett.
Rushmore, David Barker.

Associate Members.

Bisacre, Frederick Francis P.
Hamlin, Ernest John.
Schüler, Leo.

Associate.

Jenkins, William Lionel.

Graduates.

Fraser, George Victor Ross.
Marchinton, William Franklin.
Murphy, Gerald Hope.
Ramsay, Alfred John.
Sheppard, John Harding Donald.
Stokes, William Gordon.

Students.

Buchanan, George McDonald.
Eagle, Frank Walter.
Housden, Harold Stanley.
Janmoulle, Edward Walter A.
Krohn, Vere Ronald.
Lee, James Frederick.
Lovegrove, Clifton George.
McWhinnie, Donald Rolfe.
Mathieson, Donald.
Moody, Harold Thomas.
Paul, Robert Buchanan.
Pernet, Frederick Harry.
Rhodes, Harold Percival.
Ryan, Thomas McArdle.
Shuter, Ernest John.
Slevin, Edward.
Thompson, Charles Barnard.
Young, Jun., Robert.

TRANSFERS.

Associate Member to Member.

Hoult, Wilfred.

Associate to Member.

Gridley, Henry James.

Student to Associate Member.

Moffet, John Leeson.

Student to Graduate.

Chawner, Ernest John.
Cross, Harry.
Francois, Leslie Dorey.
Glasspool, Cyril Edwin.
Jain, Banarsi Das.
Monkhouse, Walter Isaac.

A paper by Mr. H. G. Brown, Member, entitled "The Signalling of a Rapid-transit Railway : A Study of the Relation between Signal Locations and Headway" (see page 545), was read and discussed, and the meeting adjourned at 9.20 p.m.

SOME METHODS OF IMPROVING THE POWER FACTOR IN ALTERNATING-CURRENT CIRCUITS.

By GEORGE STEVENSON, Member.

(*Paper received 20th February, and read before the* SCOTTISH LOCAL SECTION *3rd March*, 1914.)

The title of the subject under discussion this evening has been chosen so as to cover as wide a range as possible. The author proposes to deal with the matter briefly from the standpoint of the user of electrical plant, and to confine his remarks to industrial installations of a capacity not exceeding 5,000 kw. It will be convenient to classify the consumers according to whether—(A) they obtain a supply from an outside source, or (B) generate their own electrical energy on the premises.

(A) PUBLIC SUPPLY.

Upon application being made for a supply of electrical energy it will be found that there is usually a special clause in the form of an agreement relating to the power factor of individual motors, or of the installation as a whole. Hitherto very little attention has been paid to this clause by engineers engaged in the electrical equipment of factories, and the consumer has been advised that it is no concern of his, and that the matter will be looked after by the supply company.

Is this attitude justified at the present time? The answer evidently depends on the geographical situation of the consumer. The author has examined the rules in respect of power factor in the case of 23 supply authorities in the United Kingdom. A few examples are given below—

1. The power factor of any individual motor on the system must not be less than 0·7 at full load under normal conditions of supply.
2. The power factor of the installation must not fall below 0·85.
3. The power factor in the aggregate shall not be less than 0·8. If it falls below this figure the right is reserved to recalibrate the meters, or otherwise to take such steps as may be deemed necessary to safeguard the system.
4. If the power factor of the installation as a whole is 0·8 or over, the scale of charges is subject to a reduction of 5 per cent. If it falls below this figure, no reduction is allowed.

The first three are obviously "blanket" clauses, and, so far as can be ascertained, no installation has yet been refused a supply on account of low power factor.

The fourth example is on more business-like lines, and it will easily be seen that in the case of a large factory having from 2,000 to 3,000 h.p. installed it is important that the wattless current should be reduced to the minimum value if the owners are to obtain their power at minimum rates. Now it is clear that considerations of price and starting torque limit the choice of motors to the asynchronous or induction type in all industrial installations, hence it is desirable to choose well-designed motors running at as high a speed as possible, and also carefully to study the power requirements of each group of machines in the factory, so that under normal conditions the motors will be running at or near full load. Fortunately the modern induction motor with its high overload capacity and pull-out torque enables this to be done in most cases, except where a large margin of power is called for on account of future extensions.

To illustrate the above points curves are given in Fig. 1 showing the power factor of a three-phase 50-cycle motor of 200 b.h.p. running at 1,480 revs. per minute, and of a similar machine at 375 revs. per minute, from which the superiority of the higher speed machine is apparent, especially at fractional loads. It will be seen from the foregoing that until the supply authorities take steps to enforce their rules it may be stated in general that it will

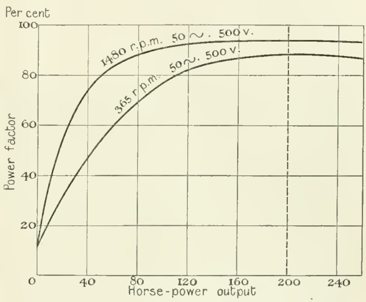


FIG. 1.—Power-factor Characteristics of Induction Motor.

not pay the consumer to take any special precautions other than the above in respect of power-factor improvement. Of course there are extra I^2R losses in the feeder cables at low power factor, but this is a point which more immediately concerns the supply engineers, and is therefore outside the scope of these remarks.

(B) PRIVATE SUPPLY.

In a paper* which the present author read before the Glasgow Local Section in April, 1908, it was pointed out that it was usual to assume an overall power factor of 0·8 for general industrial installations and of 0·75 for mines. Some representative examples taken from actual installations may be of interest.

	Plant capacity, kw.	Power factor
(1) Small iron and steel works ...	750	0·65
(2) Textile mill	4,000	0·87
(3) „ „ (special fabric) ...	750	0·7
(4) Group of collieries	—	—

* G. STEVENSON. Polyphase induction motors: the choice of type. *Journal I.E.E.*, vol. 41, p. 676, 1908.

Actual experience shows that the harmful effects of low power factor are at once evident on the generating plant, causing a reduction in the rated electrical output and introducing difficulties in maintaining normal voltage, owing to the demagnetizing effect of the lagging currents upon the alternator field magnets. Hence the great overload capacity of the steam turbine and stator of the alternator cannot be utilized because the lagging current begins to overcome the field at heavy loads, and it is necessary to

FIG. 2.

start up additional plant. Taking a concrete example and assuming a load of 1,000 kw. at 0·8 power factor, the relations between the various quantities in the circuit are shown by the vector diagram in Fig. 2, where

$P R$ = total output in kilovolt-amperes,
$= 1{,}000/0{\cdot}8 = 1{,}250$ k.v.a.,
$Q R = 1{,}000$ kw. = true power load,
$P Q$ = wattless component $= \sqrt{PR^2 - QR^2} = 750$ k.v.a.,
ϕ = angle of lag; $\cos\phi = QR/PR = 0{\cdot}8$.

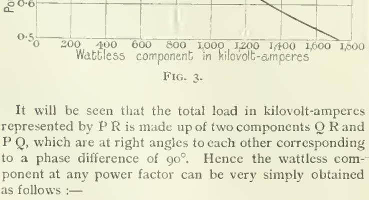


FIG. 3.

It will be seen that the total load in kilovolt-amperes represented by $P R$ is made up of two components $Q R$ and $P Q$, which are at right angles to each other corresponding to a phase difference of 90°. Hence the wattless component at any power factor can be very simply obtained as follows:—

Let A = total number of kilovolt-amperes at the given power factor,
and B = useful load in kilowatts.
Then wattless component $= \sqrt{A^2 - B^2}$.

The curve shown in Fig. 3 has been prepared from a table by Mr. W. M. Mordey. It gives the output in kilovolt-amperes which would be required for the correction to unity or any other power factor of a load of 1,000 kw. at various power factors. The abscissæ represent the number of kilovolt-amperes required at leading power factor equal to zero, *i.e.* the wattless component, and the ordinates give the corresponding power factor of the load. For example, if it is desired to raise the power factor from 0·7 to 0·85, the number of kilovolt-amperes necessary will be $1{,}020 - 620 = 400$; whereas to raise the power factor from 0·85 to unity, 620 k.v.a. are necessary.

MACHINES IN ACTUAL USE FOR POWER-FACTOR CORRECTION.

A number of different devices have been proposed for the purpose, *e.g.* electrostatic condensers, vibrators, etc., but the author is not aware that any of these are in commission in this country, and in any case he proposes in what follows to deal only with plant with which he is personally familiar.

1. SYNCHRONOUS MOTOR RUNNING LIGHT.

This arrangement may be briefly described as an alternator without steam. It has low initial starting torque, and its speed is constant, depending only on the frequency and the number of poles. A supply of continuous current is required for exciting the rotating field-magnets. For a given load there is one particular value of the exciting current which causes the motor to draw minimum current from the line. Under these conditions the current is then in phase with the electromotive force and the power factor is unity. A reduction in the exciting current results in an increase in the amount of alternating current in the stator, and it lags behind the impressed voltage. If the exciting current be increased, there is also a corresponding increase in the main current, but with the important difference that it is now a leading current and consequently can be made to compensate the lagging current, due to self-inductance, of other apparatus on the system.

Methods of starting.—For the smaller machines an auxiliary squirrel-cage winding is embedded in the poles of the field system, and the motor can then be switched on to the line through an auto-transformer starter. In practice a throw-over oil switch is used, which in the first or starting position allows the motor to run up to a speed a little under synchronism, when the switch is then quickly connected straight on to the line. It will be understood that the field winding is short-circuited—usually through a resistance, although this is not really necessary in the smaller sizes when a squirrel-cage winding is added—at the moment of starting up, and that in the final position of the main oil switch the field switch is thrown over to the continuous-current supply. Suitable interlocking devices ensure that the operations are carried out in the correct sequence.

The maximum current drawn from the line with this method is approximately the full-load current if the starting torque required is very small. A diagram of the connections is given in Fig. 4 for a 100-k.v.a. set. In larger sizes a separate induction motor is direct coupled to the machine at one end, a small continuous-current machine

being attached to the other end and used as an exciter. In view of the fact that the initial cost of a machine of this description is about £2 per k.v.a., it is evident that its use current side. The cost of this type of machine, in so far as power-factor correction is concerned, will naturally depend on the proportion of the total cost debited to the mechanical

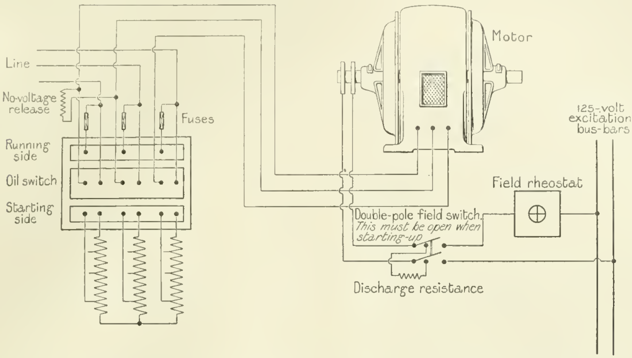


FIG. 4.—Diagram showing Connections of Starting Compensator and Field Circuit for Synchronous Motor.

is restricted to exceptional cases, but the following results obtained in the case of the small works plant referred to on page 555 (example 1) show that the method is justified. Before the installation of the synchronous motor, three steam-driven sets each of 250 kw. were required, the full-load current being 1,150 amperes per phase and the power factor 0·65 lagging. It was found impossible to maintain normal voltage under these conditions. When the synchronous motor was installed the full-load current fell to 850 amperes lagging, and the power factor rose to 0·9 lagging, the leading current given in the system by the motor being 450 amperes. This relieved the situation to such an extent that one 250-kw. set is now shut down entirely.

2. SYNCHRONOUS MOTOR WITH MECHANICAL LOAD.

If a suitable load can be provided, the practice of using synchronous motors for power-factor correction assumes a much more favourable aspect, and can be regarded as quite good under all conditions. For example, if a supply of continuous current is required, the motor and generator can be direct coupled, and thus in addition to compensating for the lagging current the machine can at the same time supply the necessary mechanical power to drive the continuous-current generator. The electrical output available for power-factor correction in addition to the mechanical output of the motor can be ascertained from the curve in Fig. 5. For instance, if 80 per cent of the rated output of the motor is used to drive a generator or other load, then 59 per cent of its rated output is available for improving the power factor of the system. Maximum utility occurs when the electrical output equals the mechanical output, *i.e.* when each has the value 71 per cent. As regards starting, it is preferable to arrange for starting up from the continuous-

load. Probably £1 to 30s. per k.v.a. would be a reasonable figure to assume.

A set of 300-k.v.a. capacity is at present being installed to

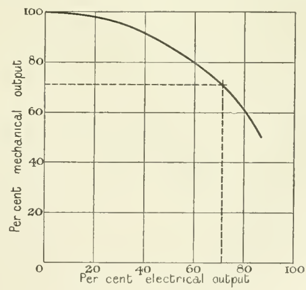


FIG. 5.

deal with case (2), page 555. No figures, however, are yet available, as the machine has not been put into commission.

3. THE PHASE ADJUSTER.

The foregoing methods are quite general in their application, and can be applied either in the main power station or in sub-stations, and they can also be used to compensate for lagging current due to one large induction motor or to a number of small motors. The increasing use

of large alternating-current motors at low speeds for industrial work, such as colliery winding gears, rolling mills, etc., has led up to the development of the phase adjuster. It can be used only on individual motors of the slip-ring type, and is not recommended for ratings less than 150 b.h.p. The principle of the phase adjuster or phase advancer is as follows. It is built in the form of a commutator machine and must be separately driven, either from the shaft of the induction motor in connection with which it is used, or from a small separate motor or countershaft. The power required is only that necessary to overcome windage and friction, and is therefore quite small, ranging from approximately $\frac{1}{2}$ to 2 h.p. according to the size of the phase adjuster.

The brush-gear is arranged for two- or three-phase rotors as required. The brushes are directly connected to the slip-rings of the induction motor, which may be said to be short-circuited by the armature windings of the phase adjuster.

The magnetizing current of an induction motor is usually supplied through the stator windings, but, if desired, may equally be furnished through the rotor windings. Since the wattless component is the magnetizing current, it will be evident that if the magnetizing current can be supplied from the rotor by the aid of the phase adjuster, no magnetizing current will be drawn from the supply system, and consequently the wattless component will be replaced and the power factor will become unity.

When the phase adjuster is connected to the slip-rings of the induction motor, the rotor current passes through the windings of the armature of the phase adjuster, causing a flux to be set up which is cut by the rotating armature itself, and a voltage to be generated which causes a current to circulate round the rotor windings of the induction motor and the windings of the rotating armature of the phase adjuster; this current is out of phase with the load current. This circulating current then becomes the true magnetizing current, replacing the stator magnetizing current or wattless component.

When the circulating current set up by the rotating armature of the phase adjuster exceeds in magnitude that which is necessary to replace the original magnetizing current drawn from the supply system, and since for a given impressed voltage on the motor the sum of the magnetizing currents produced in the rotor and stator must be constant, it follows that in the event of such excess of current, the stator must draw from the supply system a magnetizing current in the reverse sense to that which was originally required before the phase adjuster was connected, in order to neutralize the excess current produced by the phase adjuster. This may be described as drawing leading current from the system, and the result is to compensate for lower power factor in other machines which may be connected on the same feeder as the motor in connection with which the phase adjuster is used.

Method of starting.—The main induction motor is started in the usual way through a liquid or metallic resistance in the rotor circuit. A three-pole throw-over switch is interposed between the slip-rings and the starter, the blades being connected to the rings and one set of three contacts to the starter. The other set of contacts is connected to the three terminals of the phase adjuster. The adjuster may be belt-driven, either from the main shaft or other shaft, or direct coupled to a small driving motor. It has no fixed synchronous speed, hence the drive need not be constant.

It is preferable to start up the adjuster first. It is then running when the main motor is brought up to speed, and all the attendant has to do is simply to throw over the three-pole switch, thus disconnecting the starter and connecting the phase adjuster to the slip-rings.

There is no danger if the phase adjuster shuts down or is inadvertently connected in circuit when stationary: it can exert no torque and therefore remains stationary, the commutator easily carrying the current passing through it. It is very important, however, that the phase adjuster should not be connected to the slip-rings until the main motor is up to speed.

There are several incidental changes brought about which should be mentioned :—

(*a*) The power required to drive the phase adjuster is only sufficient to overcome windage and friction, and these losses are compensated by reduced losses in the main induction motor.

(*b*) The main motor, especially in large sizes, is smaller than normal when designed for use with an adjuster, and hence it is cheaper and slightly more efficient.

(*c*) The pull-out torque of the induction motor is greatly increased.

(*d*) The brushes of the main motor must run continuously on the slip-rings, and must be connected to the phase adjuster.

(*e*) The normal slip of the motor is increased by 1 or 2 per cent.

The initial cost of the adjuster in terms of the k.v.a. correction to the wattless component is approximately

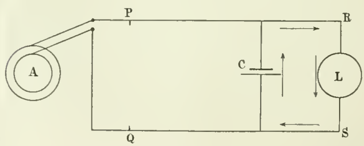


Fig. 6.

6s. 6d. per k.v.a. The following results were recently obtained by the use of a machine of this type. An air-compressor motor of 420 b.h.p. at 240 revs. per minute gave a lagging power factor of 0·82. After the adjuster was set to work the power factor became 0·85 leading, thus compensating for a low power factor on other motors on the circuit.

There is one important point in connection with any of the foregoing methods of power-factor improvement which is of considerable importance, namely, the position of the machine with respect to the generating plant and mains. If it is desired to relieve the mains as well as the generators, then whatever type of machine is employed it must be placed as close as possible to the load which gives rise to the wattless current. Referring to Fig. 6, if A is the alternator, P and Q the mains, L the load, and C the adjuster, then the wattless current or a portion of it will

flow in the direction shown by the arrows. If, however, the adjuster were connected at the points P and Q then the wattless current would circulate in the circuit P R S Q. Hence only the generators can be relieved of wattless current when the compensating plant is in the main power station, and as the saving in long feeder cables in a large network will generally exceed all other economies combined, it is essential that in such cases the adjuster or synchronous motor be installed close to the load which causes the low power factor.

Discussion.

Mr. J. Caldwell: I should like to draw the author's attention to the use which has been made of static condensers for improving the power factor. The Midland Electric Corporation's installation of condensers was referred to in the discussion on Dr. Kapp's paper,* and in view of the prevailing opinion that condensers are unreliable, it is interesting to learn that no trouble has been experienced in that case. I think there are two points of view in regard to the author's question as to the justification of the present attitude of consumers in omitting to improve the power factor of their installations and incidentally that of the supply company's system also. The consumers' view is that if the power company's system has a low power factor it is the company's concern to improve the power factor by installing condensers or a synchronous motor at suitable positions in the network. On the other hand, if it is desired that consumers should improve the power factor of the supply system they will have to install synchronous motors or fit phase advancers to induction motors larger than 150 b.h.p. As it is probable that motors of such a size would be supplied at high pressure by a power company, the induction motor would be the most suitable type to use, even though it has a low power factor. The power company might certainly grade their charges for current according to the power factor, although this method would introduce complications in measuring the extent of the improvement in order that credit might be given for it; but as the addition of a phase advancer would do away with the simplicity and reliability of the induction motor, I think it will be extremely difficult to make consumers appreciate the value of power factor improvers and go to the expense of fitting such auxiliary apparatus. If the power companies will not incur the necessary capital outlay involved in fitting phase advancers to customers' machines, although they would be the gainers thereby, I certainly think that they should make some reduction in their tariff where phase advancers are installed. In the case of a private supply the conditions are somewhat simplified as the whole installation is under one control. An instance of the economy that may result from improving the power factor is that it has been found possible to increase the power load at collieries by raising the power factor, difficult and costly additions to the existing cables being thereby saved, while at the same time the capacity of the generators and motors has been increased and better pressure regulation has been obtained.

Mr. J. S. Nicholson: I should be glad if the author would explain the use of the stator windings of the phase advancer, as they appear to be unnecessary. As the frequency of the currents in the phase advancer will be very low, there should be no great difficulty with the commutation; it would be interesting, however, to hear how these machines behave in practice. I agree with Mr. Caldwell that the cost of using condensers should not be very much greater than that of several of the appliances mentioned by the author. I have had considerable experience on a small scale with condensers and have usually found them very reliable if certain precautions are observed; and bulk for bulk I believe they will compare very favourably with phase advancers. There is no reason why condensers should continue to be so expensive, but the present demand is probably too restricted to allow manufacturers to lower the prices. In my opinion engineers have already in the condenser an excellent means of improving the power factor of many alternating-current circuits.

Mr. Nicholson.

Mr. J. A. Robertson: I have been fortunate in supplying about 90 per cent of the power load in Greenock through rotary converters, and have therefore experienced no trouble with low power factors. In one case where a power load of 600 kw. is taken from transformers, the power factor at the consumer's switchboard is 70 per cent, but by over-exciting the rotary converters in another sub-station the power factor at the supply station is kept at unity. In most cases the low power factor is due to incorrect design or proportioning of the consumer's plant, and the supply authority is quite justified in stipulating a minimum power factor. In the case of winding engines and rolling mills special terms should be made to suit each case. If power factor correctors must be used, the proper place for them is on the consumer's premises, or in an adjoining sub-station, so as to keep down the expenditure on feeder cables. It is usual now to specify that generators shall give full-load output at a lower power factor than unity, and it is probable that the extra cost of a generator designed for the lower power factor would be less than the cost of any type of phase adjuster installed at the station. The figures of relative cost quoted by the author show that the phase adjuster will in most cases be cheaper to install than the synchronous motor. With regard to condensers, I believe there is a difficulty in making them in such large sizes except at great expense.

Mr. Robertson.

Mr. W. L. Spence (*communicated*): No reference is made in the paper to the use of rotary converters for improving the general power factor. A rotary converter is neither a synchronous motor running light nor a synchronous motor with mechanical load; it is about halfway between the two—a synchronous motor with an electrical load—and it is capable of being quite effectively used for the purpose in view. I have been connected with two large installations, both steel-rolling mills in the Glasgow district, where rotary converters of 300 kw. and 500 kw. respectively are used to improve the power factor of the supply to three-phase induction motors. There can be no doubt of the advantages of power factor improvement when the supply is from isolated generating plant, but until power supply companies and municipalities make real and substantial concessions for high power factors there is little or no inducement to the consumers on public

Mr. Spence.

* G. Kapp. Phase-advancing. *Journal I.E.E.*, vol. 51, p. 243, 1913.

Mr. Spence. supply mains to do anything in regard to power-factor improvement.

Mr. Ker. Mr. W. A. KER (*communicated*): I should like to point out that the power factor improver not only reduces the wattless current, but that it may also effect a reduction in the coal bill. I think that the synchronous motor referred to by the author is one for the introduction of which I was responsible. The load at the works in question necessitated three steam alternators being run continuously at nearly full current, but at a power factor of from 0·6 to 0·65. When the synchronous motor was installed the current was reduced, as the author says, from 1,150 amperes to 850 amperes, and the power factor rose to 0·9, still lagging. This allowed one steam alternator to be shut down and kept as a stand-by. Owing to the fact that the two remaining steam alternators were working at or near full load, their steam consumption was considerably improved, and it was found possible to shut down one of the five boilers, with the result that the fuel bill was reduced. It had originally been intended to install a fourth steam alternator as a stand-by at a cost of about £1,200. In place of this, however, the synchronous motor, costing about £300, effected the same purpose and reduced the fuel bill. Still better results would have been obtained if it had been possible to place the synchronous motor near the load, which consisted of a number of motors running lightly loaded; but owing to the large number of circuit cables of considerable length leading from the main switchboard to the motors it was only feasible to place the synchronous motor in the generating station itself, thus improving the power factor of the alternators but leaving the cable loss as it was before. The machine has given every satisfaction since it was installed.

Mr. Anslow. Mr. F. ANSLOW (*communicated*): The author's summary of the steps that have been taken by various power companies to cope with this question of power factor improvement is interesting, but the first three methods appear to be too academic to have any beneficial results. To specify what the power factor of any installation must be, particularly in the case of ironworks or collieries, is to specify an almost impossible condition. The conditions under which the motors for such installations have to work render their construction such that to attempt to secure a high inherent power factor is diametrically opposed to their satisfactory operation. The matter is purely a commercial proposition, and if the power companies will deal with it as such and on the lines indicated in the fourth example cited by the author, there can be little doubt that the point will be appreciated by the consumers, and that the results will be beneficial both to the supply authorities and to the consumers, notwithstanding the fact that the capital outlay of the latter may be somewhat increased. In dealing with the improvement of the power factor by means of a synchronous motor the author shows in Fig. 5 what proportion of the energy is available for mechanical power after the lagging current has been compensated for, and also that the best results are obtained when the electrical output equals the mechanical output, each having the value 71 per cent. It occurs to me, however, that it would be difficult under actual working conditions to maintain this proportion, especially when the mechanical output from the motor is used, say, for driving a generator for supplying continuous current for motors or other fluctuating loads. It would appear that unless the mechanical load on the motor is of a constant nature there would be considerable variation in the results obtained; and if a steady load is an essential condition, the use of this arrangement must necessarily be somewhat restricted. My experience of phase adjusters for colliery winding-gear and rolling-mill motors gives me the impression that it is extremely difficult to obtain satisfactory results with them when used for such purposes. In the case of the former, a liquid or similar type of starter is required for starting, and in the case of the latter, automatic or permanent slip resistances are frequently necessary to cause the speed of the motor to drop sufficiently to allow the energy of the flywheel to be utilized. I should be glad if the author would state, first, if it is possible to have continuously in circuit with the starter and regulator the phase adjuster which he describes, and, secondly, what would be the effect of, say, a 15 per cent slip on a plant designed to give unity power factor with normal slip.

Mr. Seddon. Mr. E. SEDDON (*communicated*): The existing rules with regard to consumers' power factors vary considerably with different authorities, and none of the examples taken appear adequately to meet the case. I think one way of making the consumer take an interest in the power factor of his load would be to have a scale of charges depending on the power factor, the charge being a minimum with unity power factor. So far as the central station is concerned, the correction of power factor is very important. Years ago it was the general practice to install alternators designed for a power factor of about 0·8, which certainly met the case when the industrial load was small compared with the lighting load; but with the present large induction-motor load the power factors have fallen so low that the older machines cannot be economically run unless provision be made to relieve them of their wattless current. As the author shows, there are many ways of correcting for power factor, but where the undertaking has no traction or other converting sub-station, the correcting apparatus must be placed either in the generating station or on consumers' premises. There are cases where a large consumer requires a continuous-current supply for electrolytic or other purposes; this provides an opportunity for the engineer to try and arrange for a synchronous motor-generator set with the motor designed for a large k.v.a. capacity, compared with the requirements of the supply, so as to give a leading current to the line. At a power factor of 0·8 the total current for doing certain work is about 25 per cent greater than would be the case with unity power factor, thus showing how important it is to relieve the feeders as well as the generators of wattless current. With regard to the installation of new generators to meet this low power factor, the tendency is to install machines with a large k.v.a. rating compared with their normal kw. output, and to provide some margin in the capacity of the exciter. The exciter has always been a trouble. The output of a large generator is frequently limited by the output of this accessory, which is often overloaded and causes trouble owing to destructive sparking, this in turn affecting the supply pressure. In the installation mentioned by the author it is very interesting to note the saving effected by the synchronous motor. I know of a case where a 1,500-kw. set could be shut down by raising the power factor from 0·65 to 0·9, but a synchro-

nous motor of about 3,800 k.v.a. capacity would be required. The starting up of a plant of this size presents a difficult problem if money is to be saved, unless arrangements could be made to run the set up to speed with a turbo-alternator and synchronize the two machines together on the busbars, afterwards switching out the alternator if it is not required. If the above capacity were split up between two or three synchronous motors it would not apparently justify the expenditure. In general, I think it can be said that it does not pay to raise the power factor above 0·9; and in conclusion I would recommend members interested in the subject to read an article by C. T. Mosman in the *General Electric Review* * for July, 1912.

Mr. G. STEVENSON (*in reply*): With regard to condensers, I would call Mr. Caldwell's attention to the remarks that I made at the outset, when I said that I only proposed to deal with machines with which I was familiar. I believe that one of the reasons why condensers have not come into more general use is on account of their excessive cost, which, I understand, approaches that of a synchronous motor running light. There is also the question of reliability, and I believe I am correct in stating that in this respect they cannot be compared with the types of machines referred to in the paper.

In reply to Mr. Nicholson, the armature winding of the phase adjuster may be considered as a closed circuit and similar to a delta-connected three-phase winding. The slip-rings of the main motor are connected to the stator coils of the phase adjuster, and the circuit is completed by the delta connection of the armature winding, which is electrically equivalent to a star winding, although it has no actual star point. The currents passing through the phase adjuster are of low frequency, and for this reason the fluxes set up in the machine will travel round the periphery at a low speed determined by the frequency in the same way as in all three-phase windings. It is possible, however, by rotating the armature at a much higher speed to cut the slowly rotating field, and in this way the generated terminal voltage is obtained. The machine exerts no torque because the position of the field in space is such that one-half of it is cut by conductors carrying current in one sense, and the other half by conductors carrying current of opposite sense. Apart from the principles of its operation, the difficulties experienced by designers have mainly been as regards commutation, but I can assure Mr. Nicholson that with the arrangement shown it has been found possible to obtain perfect commutation in actual practice.

Mr. Nicholson also mentioned that it would be much simpler to design the generators in the first instance for a low power factor; of course that is so, but I might point out that it has been the practice for a number of years now to specify a power factor of 0·8. In many instances this has been found to be too high, thus resulting in the electrical end of the set being too small for its duty, and consequently in the steam end being operated at less than its rated load. In most cases the difficulty when laying down a new plant is that one does not know what the power factor is going to be, and it is only when the plant has been set to work that difficulties arise and some method has to be adopted to cure the trouble.

* C. T. MOSMAN. Synchronous condensers. *General Electric Review*, vol. 15, p. 435, 1912.

Mr. Stevenson.

I was interested in what Mr. Robertson said about the rules drawn up by supply companies in connection with power factors. I stated in the paper that the fourth example (see page 555) appeared to be the most business-like. I am not quite sure about the legal side of the question, but I think that the first three rules set out on page 555 could not be upheld, as it seems only fair that if a consumer is penalized for low power factor he should be given a bonus when the power factor is high. With regard to the cost of the phase adjuster, I would say that the comparisons of cost are not made upon the same basis, for it is mentioned distinctly that the cost of the phase adjuster is based on the k.v.a. correction to the wattless component.

With reference to Mr. Spence's remarks, it is quite true that rotary converters are useful for maintaining or improving the power of an alternating-current supply, and the introduction of the phase adjuster is not intended in any way to supersede them. Each machine has its own special sphere of application, and the phase adjuster merely fills a gap that has previously been neglected. For instance, it is not likely that a consumer taking a bulk supply from an alternating-current system would use induction motors for the greater part of the load and then install a rotary converter and switchgear and utilize continuous-current motors for the rest of the load in order to obtain an improved power factor. This is clearly a case for the phase adjuster, where there is no necessity for transforming apparatus or for more than one type of machine. With regard to the ability of the rotary converter to supply a leading current, these machines may be classified as follows: (1) Simple rotary converter without voltage regulation; (2) simple rotary converter with voltage regulation; (3) rotary converter with booster or induction regulator for voltage regulation. It is usual with the first two types to insert reactance in series with the slip-rings on the primary side of the converter. For case (1) this is useful for limiting the current that can flow in case of a short-circuit on the continuous-current side of the converter; and in case (2) additional reactance is inserted in order to obtain voltage regulation on the continuous-current side. As is well known, the continuous-current voltage increases with an increase of the field excitation. This is produced in the following way:—The fundamental property of an increase in the field excitation is the ability to draw a wattless leading current from the alternating-current side, and the voltage across a reactance carrying leading current is added to that of the transformer supplying the rotary converter. The direct result of increasing the excitation is therefore an increase in the impressed voltage on the slip-rings of the converter, which naturally raises the continuous-current voltage in the same proportion because of the fixed relation between the primary and secondary voltages. It is therefore quite true that with simple rotary converters, or with rotary converters with reactance voltage control, an increase in the excitation for the purpose of obtaining leading current changes at the same time the continuous-current voltage. In case (3) the reactance is entirely omitted and a booster is substituted for purposes of voltage control, and in the absence of reactance there is no increase in the slip-ring voltage when the field excitation is increased. Leading currents may therefore be drawn from the supply without in any way affecting the continuous-current voltage. The main purpose of a rotary

Mr. Stevenson.

converter is to convert from alternating current to continuous current, and if power-factor-improving properties are necessary in addition, they will have to be paid for as in any other apparatus, owing to the necessity of modifying the design and increasing the capacity of the converter. The field spools are evidently larger, and the armature heating is very considerably increased, when a leading power factor is required. The armature heating at 90 per cent leading power factor is very nearly double that at unity power factor, and this must of course be provided for by additional copper in the armature of the machine, which again necessitates an increased diameter.

Mr. Anslow raises a point of considerable importance when inquiring if the phase adjuster would work in conjunction with rolling-mill motors which had an additional permanent resistance inserted in the slip-ring circuit for the purposes of producing slip under load so as to utilize the flywheel energy. The use of resistances in the rotor of an induction motor for the production of increased slip is very common, but it would be useless to insert the phase adjuster in the slip-ring circuit at the same time. This will be evident when I mention that the inserted resistances may be about 10 times the value of the rotor resistance, hence for the phase adjuster to produce the same value of wattless circulating current it would be necessary to provide a voltage of 10 times the normal amount. To overcome this difficulty the firm with which I am associated has introduced a machine which in appearance is similar to the phase adjuster, but is differently wound; it is called a "slip regulator." It produces slip in the main induction motor without introducing any resistance, and at the same time it also improves the power factor. The energy which was previously dissipated in the resistance, amounting to some 15 per cent of the output of the main motor, now passes into the "slip regulator" and is converted into useful power available as torque on its shaft. This torque may be utilized by coupling the "slip regulator" to the main motor, or to some other shaft capable of utilizing its output. The speed may be constant, or variable to a slight extent. By these means the efficiency of the main motor is very considerably improved, and the saving of energy by the "slip regulator" will very soon pay for its introduction in cases where permanent resistance is now employed. The power factor is also improved, which is a considerable advantage in rolling-mill motors, the latter being generally of very low speed.

Mr. Stevenson.

Mr. Kerr is correct in stating that the synchronous motor running light to which I referred in the paper was the one for the introduction of which he was responsible.

Mr. Seddon's suggestion, that the consumer should be charged in accordance with the power factor of his installation, is on the right lines, and as a matter of fact I understand that several large power companies are now introducing a scale of charges on this principle. With regard to the output of the exciter and field magnets being restricted by low power factors, I would refer Mr. Seddon to a statement made by Professor Miles Walker in a paper * that he read some time ago before the Institution. Referring specially to turbo-alternators, he stated that the output of the field magnets at unity power factor is four times as great as at 0·8 power factor, which I think shows very clearly the effect of low power factors on the generating plant. He also stated that a cable having 4 per cent reactive drop at unity power factor has 18 per cent drop at 0·8 power factor. The case referred to by Mr. Seddon where a synchronous motor of 3,800 k.v.a. would be required is very interesting, and, as he says, the question of the starting up of this plant would be difficult, but I think it could be got over by the use of an induction motor coupled direct to the machine and used for starting purposes only.

* M. WALKER. Apparatus for improving the power factor of alternating-current systems. *Journal I.E.E.*, vol. 50, p. 329, 1913.

EXPERIMENTS ON AIR-BLAST COOLING OF TRANSFORMERS.

By F. J. TEAGO, Associate Member.

(*Paper first received 23rd February, and in final form 2nd March,* 1914; *read before the* MANCHESTER LOCAL SECTION *24th March,* 1914.)

SYNOPSIS.

1. Transformer design data.
2. Air-blast plant.
3. Apparatus for measuring air flow.
4. Effect of size of Brabbé tube on accuracy of air measurements.
5. Methods of measuring temperature rise.
6. Cooling properties of air as affected by humidity.
7. Relation between surface temperature rise of coil and mean temperature rise.
8. Air and "fogged" atmosphere as cooling media.
9. Rating of transformer as affected by air blast.
10. Appendixes and bibliography.

The following experiments were made on one of a pair of single-phase transformers of the core type designed and built in the Electrical Engineering Department of the University of Liverpool, in order that accurate information could be obtained as to the relation between the "heat rating" and the quantity and condition of the air. The two transformers are very similar in design, the most important difference between them being that one has a rectangular core with one ventilating duct, and the other a chamfered core without a ventilating duct. The experiments to be described were made on the transformer having the rectangular core. The chief particulars of the apparatus are as follows :—

TRANSFORMER.

Output.—12 k.v.a., $\cos \phi = 0{\cdot}8$, 200 volts (ratio 1 : 1), 50 ∿.

Core.—Rectangular, net cross-sectional area 7·75 sq. in., $B_{max.}$ 80,000 lines per sq. in., plates 0·02 in. Stalloy, one ventilating duct 0·407 in. wide, net weight of iron, 82 lb.

Coils.—Sandwiched, P.S.P.S.P. per limb.

Primary : 6 coils, 24 turns each, strip 0·63 in. × 0·0472 in.

Secondary : 4 coils, 36 turns each, strip 0·944 in. × 0·02955 in.

Current density 2,200 amperes per sq. in. (R.M.S.).

Net weight of copper, 48 lb.

Estimated amount of air, for mean coil rise of 50° C., with inlet air at 15°—20° C., equals 5 cub. ft. per sec.

AIR-BLAST PLANT.

Fig. 1 shows the arrangement of the air-blast plant. The air enters at the fan inlet, passing through the baffles in the air pipe into the air box, which is divided into two sections, the shutters A controlling the air inlet to the transformers through the openings D.

The air baffles, consisting of perforated metal and wire gauze, are placed at each end of the air pipe in the joints B and B′. The baffles at the inlet end of the air pipe are two sheets of perforated metal having 165 perforations (each of 0·0024 sq. in. area) per sq. in. At the outlet end of the air pipe the baffle is a sheet of wire gauze having 2,500 meshes per sq. in. In arranging the baffles, the object was to get as large a quantity of air as possible through the pipe with a distribution as nearly uniform as possible.

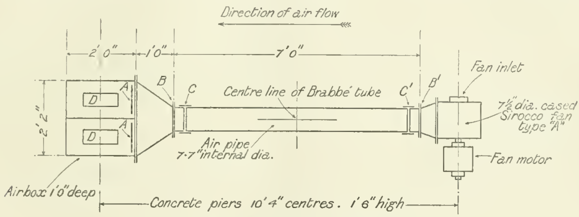


FIG. 1.—General Arrangement of Air-blast Plant.

C and C′ are leather joints in the air pipe to prevent the transmission of vibrations which would interfere with the Brabbé tube readings.

Each transformer has a sheet-iron case; these cases are connected to an air-shoot which discharges the warm air outside the building. Arrangements are also made so that either transformer can be fitted to the fan inlet.

BRABBÉ TUBE.

The relative dimensions of the Brabbé tube used (Fig. 2) are those advocated by W. B. Gregory.* This form of

* *Transactions of the American Society of Mechanical Engineers*, vol. 25, p. 184, 1904, and vol. 30, p. 351, 1908.

tube has also been largely used by Dr. Stanton at the National Physical Laboratory, and it is stated that its coefficient can be assumed to be equal to unity when the tube is properly handled.

To measure the pressure due to the velocity head of the air a special multiplying manometer was used, the details of which are shown in Fig. 3.

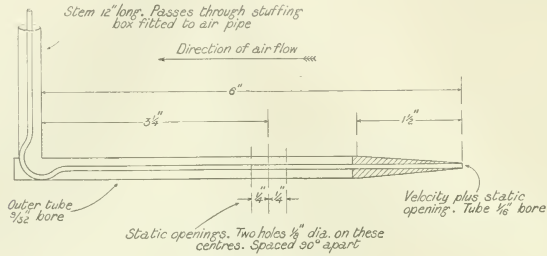


FIG. 2.—Small Brabbé Tube.

If P_1 equals the pressure due to velocity + static head, and P_2 equals the pressure due to static head alone, then,

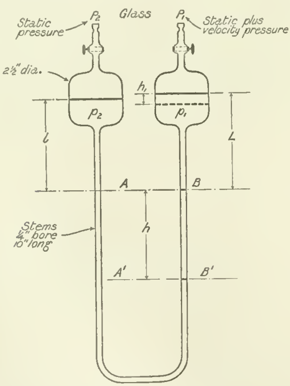


FIG. 3.—Differential Multiplying Manometer, of the type used by Dr. Stanton.

on the assumption of equal cross-sectional areas in the bulbs and a uniform bore for the tube connecting them, we have that $P_1 - P_2$, the velocity head, is given by the formula—

$$H = h\rho_2\left\{\left(1 - \frac{l}{L}\right) + \frac{h_1}{h}\left(1 + \frac{l}{L}\right)\right\}*$$

* See Appendix I.

where H is the column of water representing the pressure $P_1 - P_2$. The liquid in the left-hand limb in this case was water, coloured with a minute quantity of methyl orange. The other liquid was either carbon-bisulphide or a mixture of toluol and chloroform. The fraction H/h depends upon the ratio of the densities of the liquids in the two limbs; hence the mixture of toluol and chloroform is useful where a particular value is desired lying between the limits of either liquid used alone.

This equation for the velocity head is difficult to use on account of the large number of observations that are necessary. A calibration curve connecting H and h, obtained by placing the differential multiplying manometer in parallel with an ordinary water U-tube, is better, and was used in these experiments. One of these calibration curves

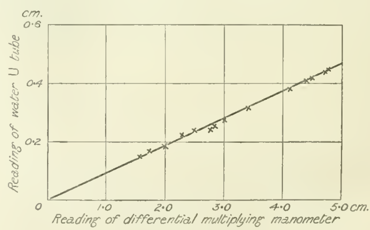


FIG. 4.—Calibration Curve.

is shown in Fig. 4, and from it the ratio is seen to be nearly 10 to 1. This ratio gave excellent results. The readings of the differential manometer are easily obtained to within 0·025 cm., that is to within 0·01 in. With a ratio of 10 to 1, this means that the readings when converted to an equivalent head of water are correct to within 0·001 in., and since the readings average 0·1 in. of water the error is not greater than 1 per cent.

AIR PIPE.

As will be seen from Fig. 1, giving the overall dimensions, the length of the air pipe between the fan and the

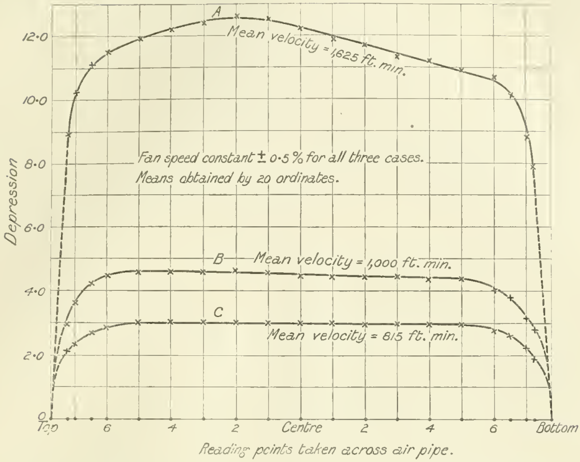


FIG. 5.—Curves showing the Effect of baffling the Air Pipe, using small Brabbé Tube.

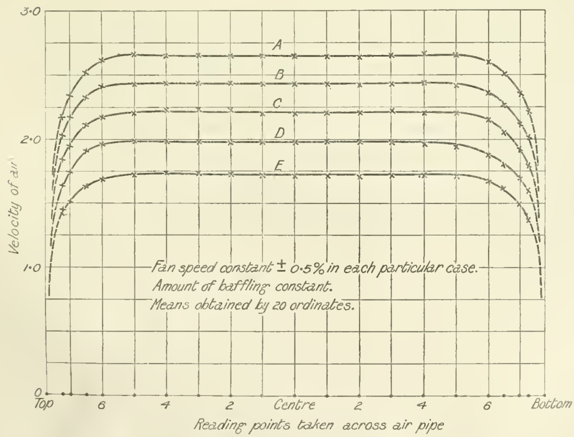


FIG. 6.—Curves showing Variation of Velocity of Air across Pipe Diameter, using small Brabbé Tube.

air box is only 7 ft. It was anticipated that considerable trouble would be experienced in the attempt to make accurate air measurements in such a short length of pipe. of the curves are proportional to the velocity of the air. Curve A was taken with the air pipe unbaffled; curve B was taken with the air pipe baffled at the fan end; and curve C

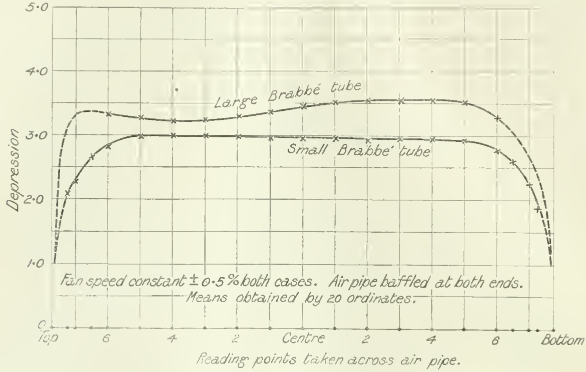


FIG. 7A.—Comparison between two sizes of Brabbé Tubes.

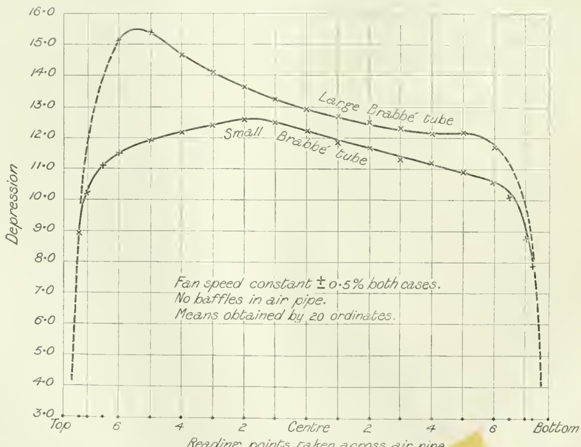


FIG. 7B.—Comparison between two sizes of Brabbé Tubes.

This was achieved by fitting the baffles at each end of the pipe; and the curves in Fig. 5 illustrate the effect of these baffles. In each case the square roots of the ordinates was taken with the air pipe baffled at both ends. The curves become flatter as the amount of baffling increases, and there is therefore less error in the observation of the

centre depression (in case the Brabbé tube is not always set accurately at the centre) as the baffling increases.

When the pipe is baffled the air flow is very steady, and the common surface of the liquids in the differential manometer is also steady; without the baffling the common surface oscillates and a mean position has to be determined. It follows, therefore, that in a short pipe baffling is necessary if the velocities are measured at the centre and multiplied by a coefficient so as to give mean velocities, and if the common surface is to be steady enough to permit of accurate readings being taken. To be efficient, the baffles must be tightly stretched.

Ratio of mean velocity to actual velocity at centre.—From the above set of curves it is seen that the ratio of the mean velocity to the actual velocity at the centre is not constant; it increases with the amount of baffling, thus showing that the baffles tend to distribute the air uniformly over the cross-sectional area of the pipe. The figures are as follows:—

Curve	Mean velocity / Velocity at centre
A	0·922
B	0·94
C	0·942

The next set of curves (Fig. 6) shows the effect of the velocity of the air flow on this ratio when the amount of baffling is kept constant, the ordinates being proportional to the velocities in this case, and the air pipe being baffled at both ends.

Curve	Mean Velocity of Air	Mean velocity / Velocity at centre
	Ft. per min.	
A	1,260	0·942
B	1,160	0·942
C	1,050	0·942
D	935	0·942
E	815	0·942

This suggests that within the limits of the velocities taken the ratio is constant for the baffled pipe. The value 0·942 was taken as being correct.

Accuracy of Air Measurements and Size of Brabbé Tube.

Preserving the relative dimensions of the Brabbé tube advised by W. B. Gregory, it was decided to ascertain the difference between the reading of a certain velocity given by a tube whose cross-sectional area is only a small proportion of the area of the air pipe and a tube whose cross-sectional area is a larger proportion. For this purpose two tubes were constructed. The smaller one had an area equal to 0·163 per cent of the area of the air pipe, and the larger one an area equal to 3·16 per cent of the air pipe. In the first case, at a velocity of 815 ft. per min., the large tube reading is 9 per cent high, indicating a velocity of 895 ft. per min. In the second case, at a velocity of 1,625 ft. per min., the large tube reading is 6·5 per cent high, indicating a velocity of 1,740 ft. per min. Now $v = c\sqrt{2gh}$, and if $c = 1$ for the smaller tube, as is assumed, then the figures indicate that for small tubes of which the cross-sectional area is about the same percentage of the area of the air pipe as that considered above, there must be considerable latitude in the design without introducing serious error when c is taken as unity.

The curves, from which these comparisons are deduced, are shown in Figs. 7A and 7B. In each case the square roots of the ordinates of the curves are proportional to the velocity of the air. The figures are as follows:—

		Large Tube	Small Tube
Mean velocity Proportional to	7A	1·782	1·622
	7B	3·453	3·233
Mean velocity / Velocity at centre	7A	0·962	0·942
	7B	0·958	0·922

Cooling Properties of Air as affected by

The first set of experiments was made in order to find out whether the varying humidity of the air had any effect

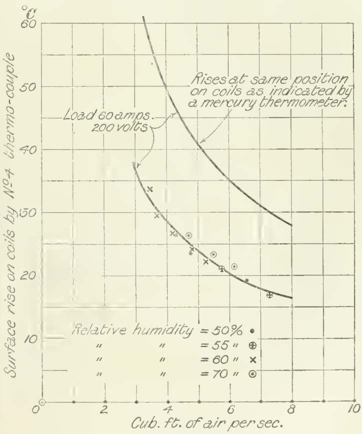


Fig. 8.—Curves showing Temperature Rise as affected by Humidity.

on its cooling properties. It was not anticipated that the effect, if any, would be great since the moisture is already in the form of vapour. The specific heat of water vapour is only about 25 per cent greater, for equal volumes, than that of air, and the amount of water vapour present, even when the air is saturated, is very small. From Fig. 8 it

will be seen that in the ordinary way the differences due to humidity are too small to be detected.

In these experiments on the effects of humidity the average number of grammes of water, in the form of vapour, per cub. cm. of air varied from $0{\cdot}8 \times 10^{-5}$ to $1{\cdot}2 \times 10^{-5}$. Expressed in litres of water vapour per cubic metre of air the amount varied from 10 to 15.*

A mercury thermometer and a toluol thermometer were tried in place of No. 4 thermo-couple (Fig. 9). The curve

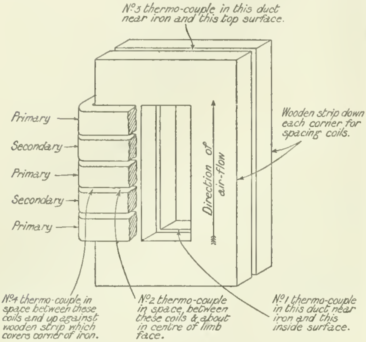


FIG. 9.—Diagram showing Positions of Thermo-couples.

shows the rise as indicated by the mercury thermometer (there were 4 grammes of mercury in the bulb of this particular thermometer). The toluol thermometer showed the same rises as the thermo-couple.

RELATION BETWEEN SURFACE RISE AND MEAN TEMPERATURE RISE OF COIL.

Since No. 4 thermo-couple is largely protected from the cooling effect of the air by reason of the wooden strip, it is likely that the surface rise of temperature of the coils is a maximum at that point. A temperature run was made to obtain the relation between the surface rise as indicated by No. 4 thermo-couple and the mean temperature rise of the coils as determined by their resistance, a continuous-current supply and Siemens precision instruments being used.

The results were as follows :—

Surface Temperature Rise by No. 4 Thermo-couple	Resistance of Coils (Volts ÷ amperes)	Mean Temperature Rise by Resistance method $t = (250 + t_0)\left(\frac{R - R_0}{R_0}\right)$
Degrees C.	Ohm	Degrees C.
4·6	0·1217	3·75
10	0·1244	9·75
15·8	0·1268	15·10
21	0·1296	21·30
26·8	0·1321	26·80
32·5	0·1346	32·40
37·8	0·1374	38·60
43·8	0·1400	44·30

* Appendix II.

Initial temperature 16·2° C. Resistance at this temperature as determined by readings of volts and amperes $= 0{\cdot}1195$ ohm, and by Post Office box $= 0{\cdot}12$ ohm.

From this it is seen that the surface temperature rise of the coils at this particular place is equal to the mean temperature rise. These results may be compared with those recently given by E. H. Rayner in the *Electrician*.* The coils in this case are double cotton covered and shellac varnished, and the temperature rises were measured on the edge of the strip as is indicated in Fig. 9.

The relation between the surface temperature of the coils, as indicated by No. 2 thermo-couple, and the mean coil temperature, is shown in Fig. 10.

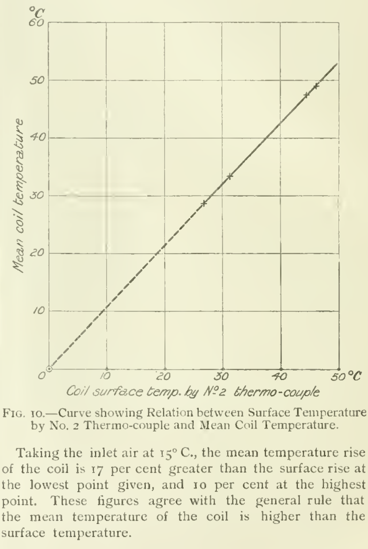


FIG. 10.—Curve showing Relation between Surface Temperature by No. 2 Thermo-couple and Mean Coil Temperature.

Taking the inlet air at 15° C., the mean temperature rise of the coil is 17 per cent greater than the surface rise at the lowest point given, and 10 per cent at the highest point. These figures agree with the general rule that the mean temperature of the coil is higher than the surface temperature.

AIR AND "FOGGED" ATMOSPHERE AS COOLING MEDIA.

A "fogged" atmosphere has been suggested as a cooling medium for electrical machinery on a number of occasions, notably by H. M. Hobart.† A number of tests were made with air rendered "fogged" by atomizing water at the inlet to the transformers, and these are compared with similar tests where the air was not "fogged."

In these experiments the average cooling effect of the water equals 300 and 600 watts respectively (see Appendix III), and the heating effect of the losses equals 900 watts. One might therefore expect the tempera-

* E. H. RAYNER. Investigation of the Temperature of Field Coils. *Electrician*, vol. 72, p. 702, 1914.

† *Proceedings of the American Institute of Electrical Engineers*, vol. 32, p. 1835, 1913.

ture rise to decrease by 33 per cent in one case, and by 66 per cent in the other. From Figs. 11, 12, and 13 it is seen that No. 1 thermo-couple shows a greater decrease, No. 2 a less, and No. 3 a decrease approximately equal to that anticipated. These results justify the serious consideration of a "fogged" atmosphere as a cooling medium

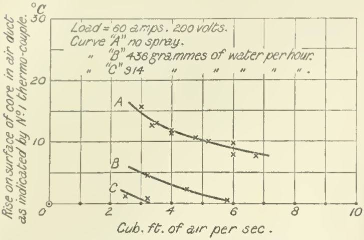


FIG. 11.—Comparison between Air and "Fogged" Atmosphere as Cooling Media. (Bottom of Ventilating Duct.)

for electrical machinery, especially where the electrical pressure is only moderately high. In the ideal case the air would be thoroughly "fogged" so as to obtain a homogeneous mixture, the amount of water used being no greater than was necessary to ensure that the water particles were not deposited on the coils, etc., as the cooling mixture

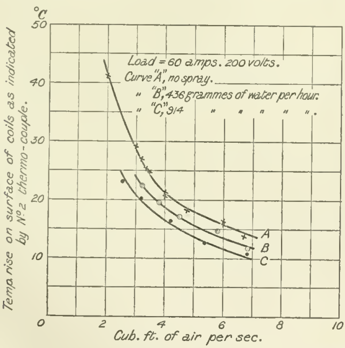


FIG. 12.—Comparison between Air and "Fogged" Atmosphere as Cooling Media.

passed through. The atomizer used in these experiments does not completely fulfil these conditions.

Plant is now manufactured capable of producing very large quantities of "fogged" air eminently suitable for cooling purposes. In one type of plant the air is washed free from dust particles and cooled, and delivered with an amount of free water in suspension which varies from zero to about two or three per cent of the total volume of the mixture according to the design. The cooling efficiency with plant of this description ought to be fairly high, but no time has been available up to the present in which to make actual tests.

As regards the insulation resistance, in these experiments no injury was done to the insulation by the water. The

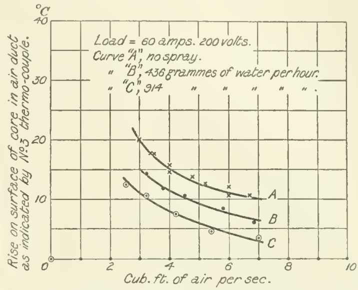


FIG. 13.—Comparison between Air and "Fogged" Atmosphere as Cooling Media. (Top of Ventilating Duct.)

insulation resistance was low immediately after a test, but this was due to the fact that moisture condensed on the bare ends of the windings. When these were dried, the insulation resistance was normal, namely, 10 megohms.

THE RATING OF THE TRANSFORMER.

The next set of experiments was conducted with the object of finding how the output of the transformer varied with the number of cubic feet of air supplied per second, the basis being a mean temperature rise of the coils of 50° C. The curves shown in Fig. 14 were obtained.

From these curves, and from the wattmeter measurements of the losses in the transformer, the following figures are obtained, and have been plotted in Fig. 15 :—

Mean Temp. Rise of Coils	60 amperes		[illegible] amperes		84 amperes	
	Cub. ft. of air per sec.	Total watts loss	Cub. ft. of air per sec.	Total watts loss	Cub. ft. of air per sec.	Total watts loss
Degrees C. 40	2·7	928	4·75	1,306	7	1,683
50	2·1	955	3·9	1,348	5·7	1,738
60	1·7	981	3·30	1,385	5	1,789

These figures suggest that for any particular value of the total watts loss—

cub. ft. of air per sec. × mean rise of temperature of coil = constant (K).

Tabulating this product for various values of the total watts loss the following figures are obtained :—

Total Watts Loss	40° C. Mean Rise	50° C. Mean Rise	60° C. Mean Rise
1,800	304	300	300
1,600	259	255	252
1,400	213	210	204
1,200	167	164	156
1,000	122	116	108

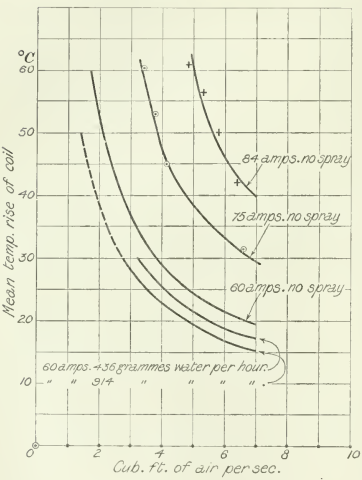


FIG. 14.—Curves showing Mean Temperature Rises on Coils for Various Loads at a Pressure of 200 Volts.

It is seen that for all practical purposes K is a constant for any given value of the total watts loss, and for a given type of transformer. This should prove of value to the designer, since all the values of K can be determined, for any one type of construction, from the product (cub. ft. of air per sec.) × (mean rise of temperature of coil) at two different values of the watts loss, since the relation is practically a straight line (see Fig. 16).

By extrapolating these curves it is found that for a load of 8 k.v.a.* no air at all is required, and for 20 k.v.a. 9 cub. ft. of air per sec. is required. These two estimated points have been plotted with the three actual points for 12 k.v.a., 14·6 k.v.a., and 16·8 k.v.a. in Fig. 17, which gives the rating of the transformer for various quantities of air.

Only one "water spray" point has been plotted ; this

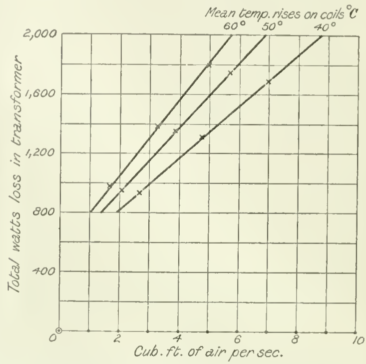


FIG. 15.—Curves showing the Connection between Total Watts Loss and Cub. Ft. of Air per Sec. for various Mean Temperature Rises on Coils.

shows a marked improvement in the rating of the transformer.

The improved rating is about 10 per cent at this point, but for the same quantity of water it will decrease as the

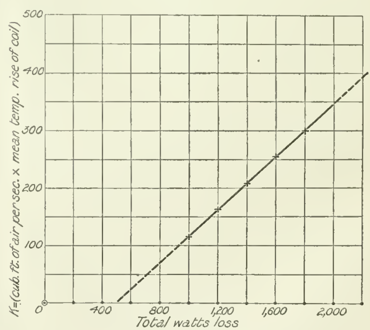


FIG. 16.—Curve showing Relation between "K" and Total Watts Loss for the type of Transformer described.

rating increases, since the cooling effect of the water becomes relatively less important.

In the near future it is hoped that the results of similar tests on the transformer with the chamfered core and no air duct will be available.

* 8 k.v.a. at 200 volts, with no air, gave a mean temperature rise of the coil of 50° C. by actual subsequent test.

In connection with these experiments the following general statements may be made :—

1. The temperature rise of the transformer is independent of the temperature of the inlet air within ordinary limits, provided that the surfaces to which the heat is radiated, that is the walls, etc., of the room, are at the air temperature.

2. Variations in the barometric pressure only affect the temperature rise to a small extent, and the correction is negligible for the small variations in the barometric pressure from day to day.

3. The humidity of the air, up to the point of saturation, has no appreciable effect on the temperature rise.

The accuracy of these statements is borne out by the results given in the various papers referred to in the bibliography.

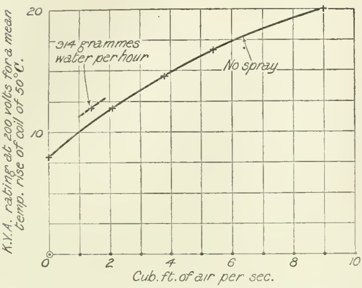


Fig. 17.—Curves showing the Connection between "Heat Rating" and Quantity of Air, with and without Water Spray.

In conclusion, the author wishes to thank Dr. E. W. Marchant for the many valuable suggestions that he has offered during the preparation of this paper, Mr. F. J. Tindall for the very valuable help that he has rendered in taking observations and working up results, Mr. J. F. Gill for the particulars regarding the differential multiplying manometer, Mr. J. K. Catterson-Smith for the details of the electrical design of the transformer, and the Council of the University of Liverpool for the special apparatus supplied.

APPENDIX I.

Differential Multiplying Manometer.

Let $\rho_1 =$ density of liquid in right-hand limb,
$\rho_2 =$ density of liquid in left-hand limb,
$a =$ cross-sectional area of small part of tube,
$A =$ cross-sectional area of large part of tube.

When $P_1 = P_2$, let A B be the common surface.

Now $\rho_2 l = \rho_1 L$, $\therefore \rho_1/\rho_2 = l/L$.

When $P_1 > P_2$, let $P_1 - P_2$ be represented by a column of water of height H, and let the common surface be A′ B′.

Then since $h_1 = h\,a/A$, we have—

total pressure in right-hand limb above common surface $= H + (\rho_1 L - \rho_1 h\,a/A) + \rho_1 h$,

total pressure in left-hand limb above common surface $= (\rho_2 l + \rho_2 h\,a/A) + \rho_2 h$.

These are equal,

$$\therefore H = \rho_2 l - \rho_1 L + \rho_2 h\,a/A + \rho_1 h\,a/A + \rho_2 h - \rho_1 h,$$

and since $\rho_2 l = \rho_1 L$,

$$\therefore H = h\left\{(1 - \rho_1/\rho_2) + (1 + \rho_1/\rho_2)\,a/A\right\}\rho_2.$$

Putting $\rho_1/\rho_2 = l/L$ and $a/A = h_1/h$,

$$\text{we have } H = h\left\{(1 - l/L) + (1 + l/L)\,h_1/h\right\}\rho_2.$$

If the liquid in left-hand limb is water, then $\rho_2 = 1\cdot0$, and

$$H = h\left\{(1 - l/L) + (1 + l/L)\,h_1/h\right\}.$$

APPENDIX II.

The Weight of a Volume of Moist Air.

Let $H =$ barometric height in mm.,
$T =$ absolute temperature, °C.,
$e =$ pressure of the aqueous vapour in mm.

From Dalton's laws this means calculating the sum of the weights of a volume of dry air at a pressure of $(H - e)$ mm. and absolute temperature T, and an equal volume of aqueous vapour at e mm. pressure and absolute temperature T.

1 cub. cm. of dry air at 0° C. and 760 mm. $= 0\cdot001293$ grammes.

Specific gravity of aqueous vapour, referred to air at same temperature and pressure $= 0\cdot622$.

Mass of 1 cub. cm. of dry air at T° C. and $(H - e)$ mm. pressure $W_1 = 0\cdot001293 \times \frac{273}{T} \times \frac{H - e}{760}$.

Mass of 1 cub. cm. of dry air at T° C. and e mm. pressure $= 0\cdot001293 \times \frac{273}{T} \times \frac{e}{760}$.

$\therefore$ mass of 1 cub. cm. of aqueous vapour at T° C. and e mm. pressure is $W_2 = 0\cdot622 \times 0\cdot001293 \times \frac{273}{T} \times \frac{e}{760}$,

and $W = W_1 + W_2 = 0\cdot00046446\,(H - 0\cdot378e)/T$.

Also since 1 cub. cm. of water $=$ (approximately) 1 gramme at any temperature, $\therefore$ 1 in. of water $= 1/W$ in. of moist air.

APPENDIX III.

Cooling Effect of Water.

If Q represents the total quantity of heat required to raise a mass of water from 0° C. to t° C. and then evaporate it, we have according to Regnault that—

$$Q = 606\cdot5 + 0\cdot305\,t \text{ calories per gramme,}$$
$$\text{or } Q = 606\cdot5 + 0\cdot305\,t - t',$$

where $t =$ temperature at which the water is evaporated, and $t' =$ initial temperature of the water.

APPENDIX IV.

Method of making Heat Runs for Temperature Rise.

The final temperature rise in all cases was obtained by running the plant for intervals of time sufficiently long to reach the desired state, keeping the working conditions as constant as possible throughout these intervals. The plant is not of large capacity, and from three to four hours was found long enough to reach the first steady point for some particular value of the load current with the maximum amount of air possible for accurate measurements (7 cub. ft. per sec.). When this final rise had been reached the amount of air was cut down by about 1 cub. ft. per sec., the load being kept constant, and the next rise was obtained.

This run would occupy about $1\frac{1}{2}$ hours, and was immediately followed by one with less air, and so on until the final rise was as high as that required, this process being repeated for different values of the load current.

Theoretically, the time required to reach the final rise is very great, but the observations were carefully made when approaching the steady state, and may be taken to be within 1 per cent of the true values.

On a few of these runs the method suggested by Dr. S. P. Thompson for estimating the final temperature rise was tried. On eliminating the preliminary "kick" by drawing a fair curve through the points obtained, the final estimated rise was in every case practically identical with the actual observed final rise.

APPENDIX V.

Method of obtaining the Ratio $\frac{\text{MEAN}}{\text{CENTRE}}$ Velocity.

Assume the air pipe divided up into narrow annular rings of equal length.

Let x = width of annular rings,
R = radius of air pipe,
V = mean velocity of air through pipe,
v = mean velocity of air through one annular ring,
d = mean diameter of this annular ring;
then $\pi d x$ = area of annular ring,
$\pi d x v$ = quantity of air through annular ring,
$\pi x \Sigma d v$ = total quantity of air through pipe,
πR^2 = area of air pipe,
and $V = \frac{x}{R} \Sigma \frac{d}{R} v$.

That is, the mean velocity is obtained by summing the products $\frac{d}{R} v$ and dividing the result by the number of annular rings.

The air pipe was divided into 10 annular rings, each 0·385 in. wide, in these experiments.

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Discussion.

Mr. Frith.

Mr. J. Frith: The whole subject of air-cooling interests me very much, and I think that it will become increasingly important. Though the air-cooled transformer is rather a thing of the past, the oil-cooled type being so much better for high-tension work, a great deal of the information given in the paper can be applied to air-cooling of other electrical apparatus, and I am convinced that in a few years the idea of running a machine in the ordinary atmosphere of the engine-room will be looked back upon with surprise. So much is now known about commutation that the limit of the output of the continuous-current machine is no longer a question of commutation, but almost entirely one of temperature rise; and to run a machine without proper ventilating ducts seems to me to be blameworthy, since a much greater output can be obtained from a machine where proper provision is made for ventilation. It is possible that we may eventually adopt a suggestion that I made some time ago, of compressing the air outside and

letting it expand into the case of the machine. This seems to me to carry the heat away in a controllable form. Mr. Cramp, who is very interested in that part of the paper dealing with air velocity measurements, wished me to congratulate the author on the use of baffle plates. The resulting curves given in Fig. 6 are exceedingly good, and the very regular velocity curves across the tube up to the sides are very good experimental results, and they have advanced the science of air measurements very considerably. It was always a trouble to measure the unequal velocity across the air ducts, and the baffle plates seem to do their work admirably. I see that the author finds the coefficient of the ratio of the mean velocity to the velocity at the centre to be something over 0·9. There, I think, Mr. Cramp would agree with him. Most authorities place the coefficient somewhere between 0·6 and 0·9, but Mr. Cramp's results give a value of about 0·9. The fact that the two Brabée tubes of such different sizes give such a near approximation is rather extraordinary ; I should have expected this to be much more influenced by the diameter of the air tube.

Mr. H. MAWSON : I am particularly interested in the first part of the paper, namely, that dealing with the measurement of air quantities. Only quite recently I have been carrying out a series of experiments on a fan where it was necessary to measure the quantity of air discharged. The Sirocco fan was of 1·5 h.p. and ran at a normal speed of 900 revs. per min., but unlike the one used by the author it discharged into a square duct 10 in. by 10 in., and in order to find the amount of air flowing it was necessary to connect the mean velocity of flow with the velocity measured at the centre of the duct. For this purpose a Pitot tube very similar to the Brabbé tube employed by the author was used, but the manometer was different, being a sloping tube at an angle of $\sin^{-1} 0{\cdot}1$ with the horizontal, thus giving a magnification of 10 upon the ordinary water U-tube. A further magnification was obtained by using paraffin of density 0·825 ; this was found to flow more freely in, and did not stick to the walls of the tube, which was of about $\frac{1}{16}$ in. in bore. This manometer worked well and gave satisfactory results. In finding the mean velocity across his circular duct the author has confined the movement of his Pitot tube to one diameter, assuming—which in the case of a circular duct is a fairly legitimate assumption—that what occurs on one diameter occurs on all diameters. With a square duct, however, no such assumption could be made, as the corners produce a marked effect upon the velocity of flow in their region. In order to get over this difficulty I had a tube constructed so that it could move both horizontally and vertically, and could be placed in any position over a half-section of the duct. The method which was followed was first to traverse with the tube a vertical line passing through the centre of the duct, taking readings of the velocity heads at a number of points along this line. The tube was then moved a convenient distance to one side of this line in a direction at right angles to the direction of flow, and a number of readings were again taken along a vertical line. In this manner the half-section of the duct was covered and in all 120 different readings were taken. On each of these vertical lines as a base the velocity heads were plotted and the mean was found for each line. These mean values were then plotted along another line taken at right angles to the direction of flow, and were set up at distances differing from one another by the distances apart at which the vertical lines traversed by the tube had been taken. The mean of this curve was estimated and hence the velocity head over a half-section of the duct was obtained. The square roots of all the velocity heads measured was found and these were also plotted in a similar manner, the mean value then being determined. This last result gave an indication of the mean velocity in terms of the velocity at the centre, and the former result gave the value of the mean velocity head compared with the velocity head measured at the centre of the duct. In the experiments referred to it was necessary not only to vary the speed of the fan but also its output, and it was customary in fan experiments to separate the energy of discharge into two parts, one being that utilized in overcoming the static pressure head and the other that used in creating the velocity head, and it was for this latter purpose that the mean velocity head was calculated. In order to get smooth curves it was necessary to resort to baffling, but the mesh which was used was much more open than that used by the author and had only 100 meshes to the square inch. When the fan was running at the lower speeds and the velocity of flow was small, very smooth curves like those shown in Fig. 6 were obtained, and for these cases it was found that the mean velocity of flow was 0·92 of the velocity as measured at the centre of the duct. The mean velocity head was seen to be 0·855 of the velocity head measured at the centre. At higher fan speeds and greater velocities of flow, even with the baffles, the smooth curves were not obtained, but curves more like the upper one in Fig. 7B were found. Having noticed in some tests on fans that instead of finding the mean velocity head in order to obtain the kinetic head some experimenters had taken the square of the mean velocity to obtain this value, for curiosity I worked out the two values. The mean square value gave a coefficient as stated of 0·855 and the square of the mean value one of 0·846 ; the latter though scientifically incorrect was not very far in error. The author apparently was in the fortunate position of being able to destroy some nine-tenths of the energy of his fan in order to get the remaining tenth steady, for excessive baffling was like putting a high resistance in the circuit. If his object had been to test the fan this could not have been done, for he would have destroyed most of the energy in order to obtain steady motion. In the testing of fans I believe that as steady flow cannot be obtained without a great deal of baffling, a better method would be to discharge the air into a large box where its velocity would be destroyed, and then allow it to flow through an orifice where at the same time the difference of pressure head on the two sides could be measured. Provided the cross-sectional area of the orifice was less than 1/20th part of that of the box, consistent results could be obtained.

Mr. C. C. ATCHISON : I notice that on page 563 it is stated that two transformers are cooled by air passing through a single duct ; apparently that air has also been cleaned with some apparatus at the entrance to the duct. I have recently had to deal with this question in connection with air cooling for generating plant when installing one cooling plant for three different machines. At the time when this matter was first considered the air passing through one cooler and along a number of ducts to the individual machines seemed to be satisfactory, but lately there appears to have been

Mr. Atchison. some trouble in certain cases on account of the machines not taking the same amount of air. If all three machines are working, each drawing equal quantities of air, everything operates satisfactorily, but if one of the machines is not taking the same amount of air as the others, or if only one machine is working, the eliminator plates may not then be thoroughly effective. In order to get over this difficulty it is found necessary to carry division plates not only through the eliminator section but also completely through the whole filter. There are a number of types of machines arranged for air cooling and cleaning purposes, and the process of first "fogging" the air and then taking the waste moisture out of it seems as if things are being done twice over. If the air can be washed without fogging it very much there is considerably less need for the eliminator plates, and there is less likelihood of getting free moisture carried through to the generator. Two people have to be dealt with, the manufacturer of the generator, who cannot allow any free moisture in his machines, and the manufacturer of the air-cleaning plant, who has to put water into the air and then take it out. I have tried to get some standard form satisfactory to the generator manufacturer, and to which the air-filter maker could reasonably conform, and after going into the whole subject very carefully I feel that there is some uncertainty. It does seem fairly safe, however, to say that if air is to be led into a generator there is a certain margin of safety owing to the temperature of the generator tending to vaporize any small excess of moisture. I am not enthusiastic about forcing air through generators, but in some cases it is impossible to avoid bends in the ducts and to restrict them to reasonable lengths; a supplemental fan then becomes absolutely necessary. Mr. Frith said that air-cooled transformers were not going to be used. I think, however, that this remark needs modification; for smaller sizes I see no necessity to install oil-cooled transformers, but larger transformers placed in the sub-stations of supply authorities may very well be oil-cooled; whether it is advisable to place them on consumers' premises unless in a separate building is a matter which I think requires consideration. In any case, if the oil is cooled by water circulation I should prefer to draw the water through the cooling coils than to force it through, as any leakage in the latter case would tend to put water into the transformer casing.

Dr. Worrall. Dr. G. W. Worrall: I have been much interested in that part of the paper dealing with "fogged" air. There is undoubtedly a future before this system of ventilation, more particularly in the case of turbo-generators, as it not only ensures the air being thoroughly clean but also increases its cooling properties. There must of course be no loose water about, and the question whether the change of pressure and the temperature of the air in passing through the machine would cause condensation must be studied. Although it is generally considered that the presence of water vapour is detrimental to the windings, I do not think that the injury results from the water vapour so much as from what it carries. The chemical vapours usually associated with a moist atmosphere are very injurious, and exposure to them even for a short time does untold damage to the windings of an electrical machine. I have, however, known a case in which some large machines stood for two years in a moist atmosphere and had an insulation resistance of zero yet suffered no injury whatever, but the situation was free from all chemical fumes and the water vapour was pure. It is of the utmost importance that the air be cleaned in some way, as with the forced ventilation obtaining in modern turbo-generators the ventilating ducts are soon choked if the air is at all dirty.

Mr. Faye Hansen. Mr. K. M. Faye-Hansen: The author claims very remarkable accuracy for the differential manometer which he uses. I do not quite see that he can expect to obtain this accuracy when he has calibrated the apparatus by means of an ordinary U-tube manometer, as he cannot expect then to get a higher accuracy than such U-tube manometers give. I have also made a number of air tests with the same type of manometer as that described by Mr. Frith, and I have found this to act very well indeed. As to the ratio between the velocity at the centre and the mean velocity, looking at the curve I think that a mistake has been made. Taking the area of curve A, Fig. 6, I find by means of the planimeter that the ratio between the area of this curve and the area of the rectangle enclosing it is approximately 0·97. To obtain the ratio between the mean and the centre velocity, however, one has to plot a curve showing the products of the velocities and the corresponding radii as ordinates, and the radii as abscissæ. The ratio between the area of this curve and that of a similar curve with the velocities of the air at the centre multiplied by the radii as abscissæ gives the desired ratio between the mean and the centre velocity. In this way it will be found that according to curve A the ratio between the mean and the centre velocity is approximately 0·94 and not 0·972. I think it would be useful if the author in his reply would correct all his figures for this ratio in the way indicated. It would show still more clearly the improvement obtained by fitting baffles. It is very interesting to notice the large difference between the temperature measured by a mercury thermometer, by a thermocouple, and by the toluol thermometer. I have sometimes measured such differences, but have never found them so large. In this case the thermometer is of course between the high- and the low-tension coils, and therefore in the strongest leakage field. I should not expect, however, that this field in such a small transformer would be sufficient to explain the discrepancy if the mercury bulb is not exceptionally large and its contact with the coil rather poor. In regard to the curves showing the temperature rise for "fogged" atmosphere, I should like to know whether the temperature rise above the surrounding air was taken before or after the latter was "fogged." From the figures given I believe that it must be above the temperature of the air before it was "fogged," and that the reduction in the temperature of the incoming air has not been considered, so that the fogging has been credited with the reduction in the temperature of the incoming air due to this air becoming saturated. I do not, generally speaking, think that fogging increases the rate of cooling sufficiently to make its use worth the risk for high-voltage apparatus. One only obtains an increase in the rating of about 10 per cent, and the same increase in the cooling effect can be got by forcing slightly more air through. In addition there is the comparative cost of the two cases, and the risk of getting moisture on the windings which are under pressure, and thereby causing surface breakdown of the high-voltage apparatus. Of course, I do not

now refer to washing the air and drying it afterwards so that there is no free moisture when the air is carried into the machine. In this way we get the advantage that the air is somewhat cooler and cleaner and we have not the risk of getting the free moisture on the windings or other live parts. The constant K referred to on page 569 is only another way of expressing what was stated in Messrs. Symons and Walker's paper,* that the cooling effect of the air is proportional to its speed. It comes exactly to the same thing. The only difference is that Messrs. Symons and Walker's statement can be applied for somewhat wider limits. If we take a case where the amount of air flowing through is very small, so that the amount of heat which the air takes is not large compared with the amount carried away by radiation, K will be far from a constant. If the amount of air is large compared with the section through which it has to pass, K is not constant owing to the amount of heat which is being put into the air to force it through the machine. The expression given by the author must therefore be used with great caution if trouble is to be avoided.

Mr. A. E. McKenzie: A previous speaker may have given the impression that it is very unwise to install one common wet-air filter for several machines. This may be true of some wet-air filters, but it is certainly not true of them all. The station with which I am connected has installed a wet-air filter which is dealing with 50,000 cub. ft. of air per minute, and the wet-air filter is always in circuit whether there are three machines running or only one; the only thing one has to be careful about is to see that a certain portion of the filter is put on, or shut off, whenever the number of machines running is varied, so as to keep the velocity of the air passing the baffle plates constant. I make these remarks because I feel sure that the wet-air filter will shortly displace all the dry-air filters. There is very little difference in the first cost, but the cost of upkeep of the wet-air filter is very much smaller.

Mr. W. A. Bristow: I should like to ask the author to explain more fully the effect of the initial temperature on the temperature rise. He states that "the temperature rise of the transformer is independent of the temperature of the inlet air within ordinary limits." Does this mean the ordinary limit of variation which is found in this country, say 15° C., or were experiments made with air artificially heated so as to reproduce the conditions prevailing in the tropics, where it is sometimes necessary to deal with initial temperatures as high as 120° F.? It has become increasingly necessary in recent years to have some exact data on this point as many very large generators and motors are designed for service in India and other hot countries, and if the author has any exact figures with regard to this matter they would be of great interest to designers. As showing in a practical manner the relation between air cooling and output, I should like to mention a case where an enclosed ventilated generator was being tested in the presence of the buyer's consulting engineer. At 5 o'clock the 6 hours' full-load run was complete and 25 per cent overload was put on for 2 hours. The consulting engineer was considerably astonished to find at 7 o'clock that the temperature was much lower than the temperature at 5 o'clock. A somewhat minute examination of the arrangements showed that the engineer in charge of the test, being anxious to show the best results, had led a small branch from the firm's compressed-air system into the machine. He overlooked the fact that when the rest of the works was shut down at 5 o'clock the air-cooling arrangement would greatly increase in efficiency, hence the somewhat startling result.

Mr. J. L. Thompson: I should like to know why a core-type sandwich-winding transformer was used. In my opinion it is the most unsuitable type that could have been chosen, since judging from the shape of the coil a minimum coil surface is obtained for a given volume. In practice it is found that shell-type transformers having a large number of coils each with a maximum practicable surface and with distance pieces between the coils give the best results. If it were necessary to use a core-type transformer, then a concentric winding would have given more useful results; for this type would allow air ducts to be provided between the primary and secondary windings in the same direction as the flow of air, and also between the secondary winding and the core. This type would give a much greater area in contact with the flowing air, and somewhat different results as regards the temperature of the coil surface would have been obtained. With this type of winding and ventilation the curve in Fig. 10 would have been much steeper, or in other words the ratio of the mean temperature to the surface temperature would have been greater. With regard to Fig. 8 and the discrepancy between the temperatures recorded by thermo-couples and by mercury thermometers on the surfaces of the coils, I suggest that this is due to local heating of the mercury in the bulb due to eddy currents, these eddy currents being generated by the alternating leakage field passing between the coils. With regard to the positions of the thermo-couples, if couples 2 and 4 had been placed between the top two coils, higher temperatures would have been recorded. These temperatures would have been of more value than those obtained, since in any piece of electrical apparatus in which fibrous and treated insulations are used the rating is fixed by a maximum temperature and not by a mean

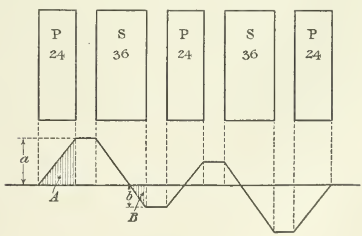

Fig. A.

temperature. The temperature here would have been greater owing to its higher position on the leg, and also owing to more heat being present on account of eddy currents in the copper of the coils. The eddy currents

* H. D. Symons and M. Walker. The heat paths in electrical machinery. *Journal I.E.E.*, vol. 48, p. 674, 1912.

Mr. Thompson.

in the copper of these coils will be more marked owing to the unsymmetrical grouping of the primary coils, which causes a heavy leakage field to cut these top two coils and the gap between. This will be seen from Fig. A herewith, in which the ordinates *a* represent the maximum intensity of the leakage field cutting the end coils, and *b* that cutting the middle coils, where the author placed his thermo-couples. The excess eddy currents therefore present in the end coils is proportional to the square of the ratio of the areas A and B. This, as will be seen, will account for an extra rise in temperature as suggested.

Professor Marchant.

Professor E. W. MARCHANT (*communicated*): One of the most important points in this paper deals with the measurement of air flow. The accuracy of the Brabbé tube as a means of measuring the velocity of air flow is of considerable importance. The problem of accurate measurement of flow along a short tube is not an easy one to solve and the method adopted of baffling the ends of the air pipe should be of value. It is well known that the eddy currents induced in the mercury of a mercury thermometer cause it to become heated, but it was not anticipated that the amount of heat so produced would be such as to double the measured temperature rise. Mercury thermometers evidently require to be used with great care when measuring the temperature rise on alternating-current machinery. The use of water in the form of fog in the cooling air is not a device which would naturally appeal to the electrical engineer. Mr. Evershed in his paper on insulation resistance* showed that water was the evil genius of nearly all insulating materials, and that when moisture was present it generally meant bad insulation. In these experiments, however, the moisture was evaporated before it came in contact with the heated coils and there was no deposit on the surface of the coils. The experiments showed that under these conditions water does very little harm, and if for no other reason they should be of value as tending to diminish the suspicion with which the wet-air filter for cleaning the air used in the cooling of machinery is still regarded. The use of a spray in the air inlet for emergency purposes when a machine has to be temporarily overrun and there is a risk of burning out the insulation, is one which might be seriously considered. A much better way of meeting such a contingency would be to increase the air blast; but this might of course be impossible in a station, whereas the starting of a spray would be a very simple matter. The paper hardly indicates the amount of work and time involved in its preparation. Each point on the curves shown in Figs. 12 and 13 involved a run, under carefully regulated conditions, of at least 2 hours and in many cases more.

Mr. Catterson-Smith.

Mr. J. K. CATTERSON-SMITH (*communicated*): I am very pleased to see the linear relations in Fig. 15, as it confirms the rule universally assumed that doubling the quantity of air through a transformer halves the rise of temperature. The author's test records in Fig. 15 show that for a 2-kw. loss a mean temperature rise of 60 degrees C. took place with 5·70 cub. ft. of air per second, and a 40 degrees C. rise with 8·70 cub. ft. of air per second. Now $60 \times 5{\cdot}7/8{\cdot}7 = 39{\cdot}3$ degrees C., which confirms the validity of the above assumption. I am not clear as to the use of the quantity

* S. EVERSHED. The characteristics of insulation resistance. *Journal I.E.E.*, vol. 52, p. 51, 1914.

Mr. Catterson-Smith.

called the constant (K). It is obvious that "cub. ft. per second × mean temperature rise" cannot alone be a constant; this is shown immediately below in the table. I prefer the more usual "cub. ft. of air per second per kw. loss for 1 degree C. temperature rise," which is nearly a constant; this, of course, is the reason for the straight line in Fig. 16. Values of this latter constant may be called q; that is $q =$ cub. ft. of air per second used × mean temperature rise observed ÷ kw. loss, and therefore for any specified rise by taking an appropriate value of q the quantity of air necessary $= q \times$ kw. loss ÷ temperature rise in degrees C. The values of q from the author's tests (Fig. 15) are with 1 kw. loss as follows:—

40 degrees	C.	temperature rise	$q = 122$
50 ,,	C.	,,	$q = 116$
60 ,,	C.	,,	$q = 100$

A comparison of these figures with some of those at present in use is of interest. Dr. Kapp* gives $q = 106$ for moderate blasts and 240 for strong blasts. In ordinary commercial practice q is often taken at 100 for large transformers of 500 or 1,000 k.v.a. ratings, whilst for smaller sizes $q = 120$ is ample. It is evident from these figures that the small laboratory plant is capable of affording data on the question of cooling which is of use when dealing with large apparatus; and I think that Mr. Teago is to be congratulated upon obtaining figures that are in accordance with practice in this respect. Mr. Roberts † gave 100 cub. ft. of air per minute per kw. loss for 30 degrees F. rise of the air in its passage through a continuous-current turbo-generator rated at 40 degrees C. mean rise, or $q = 40 \times 100/60 = 67$, which is much lower than that corresponding to a transformer, due presumably to its better heat-abstracting properties consequent upon the churning action in the machine. It seems to me that the quantity of air used must depend to some extent upon the distance between the coils and the case, and I think it might prove useful if Mr. Teago would investigate this with a view to ascertaining to what extent it is responsible for the change in the quantity q which takes place at other values of the loss. I am inclined to think that the use of "fogged" air would be very restricted, as the risks attendant to its use in ordinary high-tension power transformers would be far too great, for in spite of the author's statement that the air will not deposit water, one cannot help feeling that it might do so one day with inevitable disastrous results. If it is proposed to obtain some economy by the addition of atomizing apparatus, which must occupy space, I am of opinion that it might be found more advantageous to install a refrigerating plant and a battery of pipes to chill the cooling air, as was suggested in Mr. Roberts' paper. I gave some particulars of this plant in the discussion following that paper. The proposal is to circulate air continuously between the cooling apparatus and the transformer over and over again, so that once in circulation it may be kept in a clean and dry condition. A battery of pipes containing the cold brine can be fitted in a space of sectional area very little greater than that required in any case for the air-supply ducts. It again seems possible that the author might obtain valuable results on this cooling

* G. KAPP. "Transformers," p. 57.

† R. J. ROBERTS. The mechanical design of direct-current turbo-generators. *Journal I.E.E.*, vol. 48, p. 127, 1912.

process now that the measuring apparatus is available, and I should like to ask him to consider this proposal.

Mr. F. J. TEAGO (*in reply*): With regard to Mr. Frith's remarks, I might say that these experiments were made to obtain more definite information concerning the relation between the quantity of air supplied and the consequent temperature rise, and to bring forward the value of "fogged" air as a cooling medium, rather than to justify the air cooling of transformers. The reason why a transformer was chosen for the "fogged" air experiments is that, owing to the straight air passages, the "fogged" air has ready access to those parts which are to be cooled. If the experiments had been made on a generator, for example, the probability is that little extra cooling effect due to the water would have been observed, the reason being that practically all the moisture would be deposited in the air passages in the frame. To get the water particles into the windings, etc., the air passages must be straight and free from obstruction.

Another point to be observed is that no matter how perfectly the atomizing is done in the first place there is a tendency for the water particles to coalesce, and to be almost immediately deposited if too much water is introduced into a given quantity of air.

With reference to the value of "fogged" air as a cooling medium compared with air chilled by refrigeration, it is advisable to keep in mind the latent heat of vaporization of the water. This is so much more important than either the specific heat of water vapour, or air, that it is doubtful if a refrigerator could compete successfully, as regards cost for equal effect, with plant designed to "fog" the air.

In regard to the value of the ratio (mean velocity)/(centre velocity), the paper by R. Threlfall[*] contains the results of experiments made to fix the value of this ratio, and there the average value is stated to be 0·873.

The results of the present experiments indicate a higher value for this ratio than that given by Mr. Threlfall, and it is a very important point to notice that the investigations by Mr. Cramp confirm this higher value. The effect of the baffles used in the present experiments is to make the ratio rather higher than it would be without them.

Mr. Mawson's remarks are of great interest, and his results are very important. They, too, place the value of the ratio (mean velocity)/(centre velocity) higher than that given by Mr. Threlfall. In this case it must be remembered that a square pipe was experimented on.

In regard to Mr. Atchison's remarks, I can only say that up to the present the two transformers have never been put in parallel on the air supply, and there has therefore been no opportunity of observing their behaviour in regard to each taking its proper share of the air supplied. It will be noticed from Fig. 1 that arrangements are made so that it is possible to work both transformers at the same time if desired. With reference to the ventilating ducts, the transformer with the rectangular core has one duct, and the one with the chamfered core has no duct. Personally, I am of opinion that the most satisfactory air filter is the wet type, and that those designed on the lines of the one used by Mr. Christie at Brighton are the best of the wet types. These have the advantage that they allow the possibility of varying the condition of the air with respect to the suspended moisture. To my mind the trouble with free moisture is to get it into the windings, and not its effect on the windings. If, as stated in the paper, the "fogging" is correctly done, no moisture would be deposited on the windings, because as soon as the particles of water touched the windings they would be evaporated.

Mr. Teago.

Dr. Worrall's policy in regard to the machines that he mentions is justifiable since the danger of moisture lies almost wholly in its impurities. In "fogging" the air for use in electrical machinery it would be a simple matter to use water free from these impurities. I must point out, however, that the insulation did not get soaked in these experiments; this is borne out by the fact that when the back of the terminal board was dried the insulation resistance was 10 megohms.

With reference to Mr. Faye-Hansen's remarks about the limiting percentage error in the readings of the velocity head, the multiplying manometer was calibrated by placing it in parallel with a water U-tube, the readings of the water U-tube being very carefully taken by means of a high-power microscope. I think a possible 1 per cent error is an overestimate rather than an underestimate. The great difficulties in attempting to make accurate measurements of air flow are the oscillations of the manometer liquids due to fluctuations in the air flow, and the effect of the liquids sticking to the sides of the tubes. It is obvious that the greater the sensitiveness of the manometer the more troublesome do these things become. In the "sine" gauge it is very doubtful if the bore of the tube approximates to a straight line sufficiently well to permit of the magnification of 400 being used with any real benefit, and it is quite possible for the observation error to be larger with these high magnifications than it would be if a comparatively small magnification were used.

In regard to the mixture of air and water, if the air and water are at different temperatures before being mixed an exchange of heat will take place. Since, however, the latent heat of vaporization of the water is the predominant factor, the exchange of heat could have but little effect on the final result. The whole of the extra cooling effect of the mixture can therefore be attributed to the presence of the water particles. That the cooling effect of air is proportional to its velocity within wide limits in the case of electrical machinery is due to the churning of the air. Each particle of air must come in contact with the hot surfaces for this to be possible. The law holds, however, for the case where air is forced through narrow ducts even though the motion is not turbulent.

With further reference to the relation between the quantity of air and the consequent temperature rise, Fig. 16 shows that it is incorrect, for transformers at any rate, to write—

$$\text{cub. ft. of air per sec.} \times \text{mean temperature rise} \div \text{kw. loss} = \text{a constant}$$

It is correct, however, to assume that the product of cub. ft. of air per sec. and mean temperature rise is equal to a constant, provided that the loss remains constant. This is important in view of the present-day practice relating to the computation of the amount of air required for cooling electrical machinery.

The point was raised as to the value of the ratio (mean velocity)/(centre velocity). In Appendix V the method of

[*] R. THRELFALL. Velocities of gases in pipes. *Institution of Mechanical Engineers, Proceedings*, 1904, p. 245.

Mr. Teago. calculating this ratio is given. On checking the calculations it was discovered that the factor d/R had been inadvertently omitted. The error has been corrected in the text, and I am greatly indebted to Mr. Faye-Hansen for drawing attention to this matter.

In answer to Mr. Bristow's question, in these experiments it was only possible to observe the effect of the variation of the inlet air temperature on the final temperature rise within the limits 14 C. and 20 C. Over this range the correction to the final temperature rise is certainly negligible, but fuller information on this point can be obtained by referring to some of the papers mentioned in the bibliography.

In reply to Mr. Thompson, the reason for using core-type transformers with sandwiched coils is that they were already part of the transformer-room equipment and were the most suitable of that equipment for my purpose. To find the exact position of the maximum temperature rise it would have been necessary to explore by means of the thermo-couples the whole of the exterior surface. A complete survey on these lines would have been interesting, but a knowledge of the maximum temperature rise would not, in itself, have helped the investigation. Mr. Tea

With reference to Mr. Catterson-Smith's remarks, as pointed out in my reply to Mr. Faye-Hansen Fig. 16 shows that in the present case at all events q is not a constant. K, the product (cub. ft. of air per sec.) × (mean temperature rise), is almost constant, however, if the watts loss remains constant. Thus the use of a line such as that shown in Fig. 10 would be more accurate than the use of q.

ELECTRIC LIGHTING OF COTTAGES.

By W. FENNELL, Member.

(*Paper first received 7th November*, 1913, *and in final form 4th March*, 1914; *read before the* BIRMINGHAM LOCAL SECTION, 25*th March*, 1914.)

Electricity has for so many years been looked upon by the public—and even by electrical engineers themselves—as a very convenient but rather expensive form of lighting, that it requires considerable imagination, even to-day, to contemplate the installation of electric light in hundreds of cottages inhabited by the poorest people and rented at say 3s. to 4s. per week.

It may, and perhaps will, be said that while electric lighting would confer great benefits upon the tenants of cottages by supplying a healthy light which would not vitiate the air in already overcrowded rooms, it is not reasonable to suppose that this can be done profitably at a cost within the means of the consumer; and that any such proposal is doomed to failure, if only on the ground that such tenants are unreliable as well as careless, and would not properly use or appreciate the supply.

In introducing the subject, it may be well to set out the reasons that led to the consideration of this question. Wednesbury, like many Midland towns, is not an attractive residential area, the richer people for the most part live outside, and the workers form nine-tenths of the population. In developing the demand for electricity on the usual lines, most of the larger houses and shops were soon connected. Reduced rates for licensed premises brought almost all these houses on the mains, and the smaller shops followed when a free-wiring scheme was introduced; but not even free-wiring coupled with the rateable value system of charge, or slot meters, induced the £8 to £18 householder generally to take a supply of electricity. With these small consumers the convenience of gas for cooking and the cheapness of the apparatus are greatly in its favour. This class of consumer will not as a rule use both electricity and gas, and has no money to spare for the purchase of expensive cooking stoves; it is therefore useless to expect to make much headway until cheap electric cooking apparatus can be offered. It appeared that the limit of the lighting demand was being reached.

At first sight it seems to be hopeless, having failed to reach the lower middle class, to look to the class below—the labourer, living in a cottage. It was, however, obvious that if this class could be catered for, a very large new field would be opened, as there are hundreds or thousands of these cottages and small houses in most industrial towns. The conditions in these cottages are such that the gas stove offers no attractions. In the first place a fire is always burning in the living-room, and the stove provides hot water by means of a slung pot or kettle and has a good oven. Lighting only is required; but not only "free wiring," but free lamps are essential. Such consumers cannot afford to pay at once for the wiring; or 2s. 8d. for a lamp; and experience of the £8 to £18 householder showed that unless lamps were supplied free, the result would be the use of cheap carbon lamps, followed by disuse of the electricity supply and the installation of gas. Again, allowing a five years' life, a slot meter costs 10s. per annum. It is also a very unsatisfactory article, and repairs (or loss of revenue) are heavy.

Slot meters being out of the question, and quarterly accounts quite impossible, the author considered the possibility of establishing a weekly payment system. He therefore consulted a local tradesman doing a large weekly payment business. The report was practically as follows:—

"The poorer people are the best class of payers. A debt of only one or two shillings is a worry to them, and they will pay much better than the lower middle classes who have more assurance. It will be found that they are more easily pleased and are anxious not to give trouble; and as they are accustomed to weekly payments for rent, clothes, and furniture, they usually set aside their money regularly for this purpose before spending the balance."

In view of this very favourable report, the author felt safe in adopting a weekly payment system for electricity, and the following is a summary of the arrangements adopted.

Service Connections.

In this respect the circumstances favour the proposal. These small houses are in blocks, and one service will supply from 5 to 15 houses. The plan adopted is to put an ordinary 7/18 S.W.G. service into the most convenient house, terminating it in a service fuse. Space is allowed for fixing a meter if desired to check the consumption for each block. From the fuse a twin lead-covered cable is carried either inside or outside the houses, along the row, and is looped into each house to be supplied. If any house in a row is not to be connected, a loop is left in the wire ready to insert when the tenant decides to come on, which is almost certain when a change of tenancy occurs.

It has been found that the cost of the service averages 15s. per house, whereas the cost of an ordinary service for a few lights is about £3 8s. The saving in capital charges is therefore very considerable, and must not be lost sight of when considering the value of these small consumers as compared with ordinary consumers.

With regard to wiring, each house is provided with a wall-plug socket, which takes the sub-service wires; the plug itself is connected by means of flexible wires to a pair of bow cut-outs. This arrangement provides a double-pole fuse and switch ample for disconnecting a 120-watt installation, and is cheaper and less liable to corrosion, etc., than an ordinary double-pole switch. The wiring, which commences at the bow cut-out, is quite ordinary and requires no comment.

The cost of the wiring and fittings without lamps averages £1 10s. to £1 13s. 6d. per house. A local switch is at present allowed for each light, but the substitution of key-holders is being considered. Experiment is necessary to see whether the extra consumption due to the absence of easy switching is of more importance than the reduced cost of wiring.

Lamps.

Three lamps are supplied, two being 40-watt metal-filament lamps (one for each of the downstairs rooms), and one an 8-c.p. carbon lamp for the front bedroom. Contrary to expectation, it is found that there is no demand for light in the other bedroom or bedrooms.

With any rental system of supply it is necessary to prevent any but authorized lamps being used; and in order to do this, the simple expedient of using Edison screw caps and lamp-holders is adopted. This has been quite effective; lamps with this cap cannot be bought in small quantities, yet there is no extra expense for either holder or lamp, because it is the Continental standard. The only screw lamps stocked at the works are 40-watt metal-filament or 8-c.p. carbon; no mistake can therefore be made. When lamps are supplied free of charge it is unlikely that consumers will buy lamps by the dozen in order to defraud the supply authority. The weekly visit of the collector also acts as a check.

Financial Details.

The charges must cover the cost of supply of electrical energy, free wiring, lamps, repairs, and the expenses of collection. It was estimated that an average of about 7½d. per week per house would easily cover the cost. The cost of supplying electricity at Wednesbury is, including all charges such as interest on and repayment of loans, £7 per kilowatt of maximum load on the power station plus 0·35d. per kilowatt-hour. These figures leave a small margin. The assumption was made that the absence of a meter would mean a certain amount of waste, so a fairly high average consumption has been taken, viz. 6 hours' use of the maximum demand per night throughout the year. It was assumed that the average maximum demand at the time of the peak load, which is between 4 and 5.30 p.m., would be 50 watts; but experience has shown this to be rather too high a figure. The lamps in use are easily counted, without calling at the houses, by taking note of the illuminated windows. Visits show that the number of lamps in use between 4.45 and 5.30 p.m. amount to 108 per 100 cottages. Later on, after tea, the demand is higher, but that does not matter because the power load must be "off" when the workmen and women are at home. One is therefore certain of a high diversity factor for this demand.

Based upon a peak-load demand of 45 watts per house, and a 6 hours' use of this load per day, an annual consumption of 100 units is obtained. The cost of electricity supply is 5s. 6d. per annum for the standing charges, and 2s. 11d. for the energy consumed, or a total of 8s. 5d. The revenue at 7½d. per week amounts to £1 12s. 6d. per annum. The 7½d.-per-week average income is obtained as follows: June and July 5d., May and August 6d., April and September 7d., March and October 8d., February and November 9d., January and December 10d., so that consumers pay approximately in proportion to the use at different times of the year, and new consumers may—and do—start taking current on a fair basis at any time.

Collection is carried out on a commission basis; which has been found to be satisfactory. A collector working insurance or other business is engaged, and he knows how to deal with these consumers. Payment is made in advance on the Monday or Tuesday, and the consumer is liable to be cut off on the Monday following a failure to pay. A copy of the application form is given as an appendix to this paper.

Results.

The scheme is extremely popular; it has grown from an experimental 25 consumers to 250 within 18 months, and this without any canvassing or pushing. It is quite usual for a poor woman to call for a few forms, say a dozen, and to bring them back again signed within a week. It may be mentioned that gas is 1s. 11d. per 1,000 cubic feet, so that it cannot be said that dear gas is the cause of the success of the scheme.

The actual experience obtained with regard to the following points is of great importance.

Arrears.—These keep fairly steady and are on an average about equal to one week's rental.

Lamp breakages.—These do not average one lamp per socket per annum.

Empties.—These are no more numerous here than in other premises, and further, those houses fitted with electric light are sought after.

Disconnections.—Although consumers are in no way bound to continue the supply for a definite period, there

have been very few permanent disconnections, certainly not more than 2 per cent.

Bad debts.—These can be kept as low as desired; payments are made in advance. Even with fairly lenient treatment the bad debts have not exceeded 1 per cent.

Waste.—This subject deserves a paragraph to itself. There are several causes which tend to check waste. The first, and perhaps the greatest, is the sense of fairness which exists in the working class, and the second is the weekly visit of the collector. The consumers live in blocks, and the doings of any one tenant are known to all, so that one person at least will report waste, due perhaps to a feeling of honesty, or perhaps to differences of opinion on other questions. However, it is not to be believed that one consumer in ten will burn, say, one lamp continuously day and night, or two lamps all night, but if that is assumed, the cost of the extra consumption is 10s. per annum. Even if it is not balanced by others who use the light less than 6 hours per night, it barely exceeds the annual charge on a meter in that one case; and of course if the meter were put in every house, as would be necessary, the annual cost would be £5 for meters, to save a possible 10s. waste. As a matter of fact, the energy consumed costs so little that any possible waste can be ignored. The important point is not waste of energy, but excess maximum demand. This is easily observed, and it has been shown that it does not occur.

The revenue account works out as follows :—

			Per Annum
Electricity		s. d.	s. d.
Kilowatt charge (45 watts at £7 per kw.) =		5 6	
Unit charge (100 units at 0·35d.) =		2 11	
			8 5
Lamps			
Two metal-filament and one carbon			4 3
Repairs			1 0
			13 8
Income		£ s. d.	
52 weeks at 7½d.	s. d.	1 12 6	
Less commission, 7 per cent	2 4		
Less bad debts, etc., 3 per cent	1 0		
		3 4	
			1 9 2
Profit per consumer			15 6

The word profit here means surplus after paying all charges, including interest on and repayment of loans for machinery and mains. If these interest charges were based on the cost of extra plant and mains instead of on the old costs, the result would be even more favourable.

We may take half the profit, say 8s. per annum, and use it to write off the entire cost of wiring in four years, leaving a balance of 7s. 6d. net profit per consumer per annum for four years, and 15s. per annum afterwards.

In conclusion a net profit of 7s. 6d. per annum per consumer, or about 25 per cent of the income, after paying all expenses is a far better return than can be shown on any other class of consumers. Putting it another way, 1 kilowatt of maximum demand produces a profit of over £9 per annum, and over double that sum after four years. Many of the ordinary consumers barely produce a gross income of £9 per kilowatt of the peak demand, to say nothing of profit.

The author is indebted to the Light and Water Committee of the Wednesbury Corporation for the confidence that they showed in his recommendation by embarking on the scheme, knowing that it was an experiment. Special thanks are due to his Mains Engineer and Chief Assistant (Mr. J. P. Smith), who has co-operated in every possible way in carrying out the scheme.

APPENDIX.

Wednesbury Corporation.

ELECTRICITY SUPPLY IN SMALL HOUSES.

In order to encourage the use of electricity in small houses and to avoid the use of slot meters, the Electricity Committee have decided to give a supply without meter in small houses for three lights, for weekly payments as follows :—

June and July	5d. per week.
May and August	6d. ,,
April and September	7d. ,,
March and October	8d. ,,
February and November ...	9d. ,,
January and December ...	10d. ,,

Two lamps will be each 32 candle-power in the living-rooms and the other will be smaller, suitable for bedrooms, etc.

The wiring, lamps, and all fittings will be supplied by the Corporation on loan, and remain their property. Extracts from the Electric Lighting Acts are printed on the back of this form [Sections 16 & 17 of 1909 Act, and Sections 24 & 25 of 1882 Act]. The wiring and lamps will be kept in good order, free of charge, by the Corporation, provided they are treated with ordinary care, so the consumer has free wiring and free lamps, the only charge being the weekly rental. This must be remembered in comparing the charges with the cost of lighting by oil-lamps or gas, in which the user has to pay for lamp-glasses, or mantles, in addition to the charges for the actual oil or gas.

It will be noticed that the charges are arranged so that the supply may be commenced at any time, and the weekly charge will be a fair one for the time of the year.

Charges are payable weekly, in advance, on Mondays. Any consumer paying four weeks in advance at one time will be allowed a discount equal to ½d. for each 5d. paid. A book is provided for each consumer, in which all payments will be entered.

FORM OF APPLICATION FOR SUPPLY.

To the Engineer and Manager,
Electricity Department,
Camp Street, Wednesbury.

..........................191

I..................................of....................................
accept your offer as above to fit two 32 candle-power Lamps, and one 8 candle-power Lamp in the above house, and I agree to receive and to pay for the supply on the terms and conditions as printed hereon. I will also pay for any damage to Lamps or Fittings caused by carelessness or misuse.

Signed.......................................

Discussion.

Mr. Chattock. Mr. R. A. Chattock: While agreeing that a scheme of the kind described by the author is probably quite workable for a concentrated community, where personal touch can be maintained with the consumer, I am afraid that when applied to a city such as Birmingham, where the number of small consumers may easily reach 100,000, the personal touch would be lost, and it would be impossible to tell whether waste was occurring or not. With regard to the financial details of the scheme, I see that the author estimates that 100 units will be used per house per annum, on the basis of a demand of 45 watts per house at peak-load times. Now 45 watts represents only about 40 per cent of the number of watts installed in each house, and for lighting of this character I consider that his estimate is far too low. An average figure for the maximum demand in the case of ordinary lighting is 60 per cent of the number of watts installed: with the class of lighting referred to in the paper the diversity factor is very much smaller, and in my opinion the maximum demand would considerably exceed 60 per cent. If this is so, there is no doubt that the kilowatt charge may quite easily be doubled, whilst the unit charge will probably be increased, with the result that the estimated profit would practically disappear. As regards the unit charge, I should like to know whether the author has checked his estimate of 100 units per house per annum by means of installing check meters. It would certainly be worth while to do this in a number of instances, rather than to rely upon a pure estimate. The item of 4s. 3d. for lamp renewals seems too low in view of the figure mentioned in the paper of 2s. 8d. per metal-filament lamp. In regard to the service connection, the author mentions a switch as well as a double-pole fuse, but in the sample apparatus which he showed I did not see any switch included. I should like information on this point. I also noticed that he used a twin lead-covered cable, either inside or outside the house, along the row. I should like to know if he has any trouble in obtaining wayleaves from the owners of houses who do not propose to use electric light. I anticipate that there would certainly be such trouble if the scheme became at all widely adopted, and payments would probably have to be made for the purpose.

Mr. Allen. Mr. S. T. Allen: Several engineers have tried different schemes for supplying electricity to workmen's dwellings, and a number of such schemes have been abandoned. I consider, however, that a great deal will be done in the future in this direction, not only as a result of decreased costs and more extensive hiring powers, but also because the Health Departments of the various local authorities will more and more realize that electricity supply for workmen's dwellings is as important to the welfare of the occupiers as are good sanitation and pure food. With regard to some of the author's figures, some results given by Mr. Sillar of Colchester about nine years ago in a paper which he read before the Incorporated Municipal Electrical Association* may be of interest. Mr. Sillar's supply was metered in each house, prepayment meters being used. Taking 82 consumers, the average number of lamps per house was 5, the average revenue was $10\frac{1}{2}$d. per week, and the average profit shown to be obtainable was 8s. 2d. per consumer. With these five lamps, however, Mr. Sillar showed that the average number of units used per annum was 100. This seems to show that the author's estimate of 100 units per annum for a 3-lamp installation is liberal. With regard to the cost of services, averaging 15s. per house, it would be interesting to know how many main services the author has installed for the 250 houses referred to. His main switch does not appeal to me. I do not consider that for such houses a wall plug with a flexible attachment should constitute a main switch, especially considering the class of children to be found in houses of this character and possible trouble due to their inteference with the installation. I would strongly recommend an ironclad switch, which after all would not add much to the expense of the installation. It is stated that the substitution of keyholders for ordinary switches is being considered. I strongly recommend a wall switch for each lamp, and consider that switch lampholders are not at all suitable for such houses. Even in his printed agreement the author has restricted the users under this scheme to three lamps. This might suit some special conditions in Wednesbury just now, but if the system is to be universally adopted provision for any number of lamps should be made when drawing up the charges. The use of Edison screw-cap lamps is a very good idea and well worth copying. The author's experience that for 120 watts connected for lighting only 45 watts is recorded as peak-load demand, is certainly interesting. The mode of collecting the accounts weekly on the commission basis is certainly very good, but I am doubtful whether all authorities would agree to such a system. I think the author's balance sheet would have been more correct if it had shown the annual charges due to the wiring and the installations. He has also been too generous in only allowing four years to write off the entire cost of the wiring. This could well be extended to eight years. There is one main point in which I disagree with the author's scheme, namely, that in the main services or sub-services no provision is made for cooking, heating, or other possible loads in the future. I am not alone in holding the view that there are enormous possibilities in the future in this direction, especially when the cost of electricity supply is still further reduced and when electric cookers, heaters, etc., can be hired out at the same price as is gas apparatus at the present time. I think that in laying new mains and sub-services such loads should be allowed for, thereby preventing complications and great extra expense in the future.

Mr. Milns. Mr. W. E. Milns: Such a scheme as that of the author would doubtless be vigorously promoted in a town like Wednesbury which has a very large power supply but a comparatively small lighting load, while in other towns with a heavy lighting peak no special effort would be made to obtain this class of business. The plug switch referred to would not, I think, pass the Institution Wiring Rules. Some charge should be made for lamp renewals, say 6d. per lamp; this would be a check on any waste of current and breakages of lamps, as the consumer would know that the life of the lamp depended upon the number of hours of use. The revenue shown in the paper repre-

* A. R. Sillar. Electricity supply by free wiring and prepayment meters. *Proceedings of the Incorporated Municipal Electrical Association*, 1905, p. 119.

Mr. Milns. sents 16s. per 60-watt lamp per annum. This seems very high compared with the revenue from similar houses taking current through prepayment meters, which represents 6s. 6d. per 60-watt lamp per annum, and about 4s. 6d. per 50-watt lamp from large houses.

Mr. Holden. Mr. S. H. HOLDEN: I should like to know the method employed when disconnecting defaulting consumers. It is surprising to hear that electrical energy is anywhere so cheap that waste may be ignored. The cost of meters is, in my opinion, overestimated by the author. A first-class continuous-current $1\frac{1}{2}$-ampere meter can be obtained for not much over 30s., and alternating-current meters for less than 30s. Such a meter would certainly last 10 years and could be maintained for 5 per cent per annum, so that 5s. or 6s. per annum is ample to cover its cost. Then there are electrolytic meters, which would probably be obtainable at a still cheaper rate. The absence of a meter confines consumers to the use of current for lighting purposes. Although the use of current by such consumers for heating or cooking is not probable at present, yet if the great advantages and direct saving to be effected by the use of laundry irons were to be properly explained to these consumers they would be adopted at once, provided they could be obtained on hire at favourable terms.

Dr. Railing. Dr. A. H. RAILING: Whilst I agree with Mr. Milns that it is more profitable at the present moment to look after the £50 houses, I am of the opinion that in all the big manufacturing centres, including Birmingham, it will eventually be essential to tackle the problem of workmen's cottages. I agree, however, that local conditions play a very important part, and that the method of solution will largely depend on such local conditions. I do not agree with Mr. Holden that meters should be installed. On looking at the revenue account it is seen that the unit charge and the kilowatt charge per house come to about 8s. 5d.; the extra item of 2s. for meters, even if these are of the cheapest kind, is therefore an important percentage of the total cost, and is almost as important as the cost of lamps when considering the feasibility of such installations. Two kinds of waste have been mentioned. First, the consumer tries to use more current-consuming apparatus than he pays for, such as irons, lamps of higher candle-power, additional lamps, etc. In some supply undertakings controlled by my firm we have been trying, in order to prevent such waste, one of the various classes of current limiters which are on the market. It is an ordinary flicker limiter which can be bought for about 2s. Our experience proves, however, that the current consumption with the flicker meter has not been less than in similar installations where the flicker meter was not installed, so that this seems to prove that it is hardly necessary to use such apparatus. The second class of waste lies in the possibility that the consumer may omit to switch off his lamps. This, of course, may happen, and the estimate should allow for a certain percentage of waste. At the same time it seems hardly credible, especially if a certain amount of supervision is exercised, that wilful continuous waste should take place, especially at the time of peak load, when of course it would be most important. As a matter of fact the author shows that between 4.45 p.m. and 5.30 p.m. the number of lamps in use amounted to 108 per 100 cottages, which indicates roughly a waste of about 8 or 10 per cent. If this is the average waste, no doubt it would not pay to eliminate it by meters. As regards details, I do not particularly care Dr. Railing. for the wall-plug arrangement which the author employs, although I agree with him it is cheap: but perhaps by paying another 1s. it might be possible to obtain some cheap kind of switch-fuse which would answer the purpose. The author mentions that he used an 8-c.p. carbon lamp for the front bedroom. I do not see why he should do so. An 8-c.p. lamp requires about 30–32 watts, whereas by using 15-watt tungsten lamps, which are now obtainable, the current consumption in that room would be reduced to one-half. The author's method of preventing the use of lamps of higher candle-power, viz. by adopting Edison's screw lampholders, is of course quite effective, but if the scheme were adopted on a somewhat larger scale I am afraid that such lampholders would not be sufficient safeguard. It would, however, be easy to devise some other means. I remember, for instance, that when tungsten lamps were first introduced, and their price was comparatively high, a special device for locking the lampholder had to be devised so as to make it impossible for unauthorized persons in public buildings and streets to remove the lamps. It is a very simple device and allows a lamp to be removed only by the use of a key or special screw-driver. With regard to the collection of the money, I wonder whether a system which is successfully employed in some places on the Continent has ever been tried in this country; it consists in making the landlord responsible for the collection of the money. In the case of some large flats a fixed rate is there charged per flat, and the landlord collects the money, against a small commission, for the electric supply undertaking. Perhaps some such scheme might also be applicable in this country. In regard to lamp breakages, I agree with some of the previous speakers that a lamp should last more than one year. Perhaps if breakages are very numerous it would be necessary to take some such step as that advocated by Mr. Milns, namely, to charge a certain amount per lamp; if possible, however, I would prefer to avoid any additional charges. Success is only possible, as the author points out, if the small householder knows exactly what he has to pay per week, and therefore uses electricity in the same way as he uses water.

Mr. F. W. FOSTER: The final success of any scheme such Mr. Foster. as that outlined by the author would depend largely on the development of the $\frac{1}{2}$-watt lamp. I do not share other speakers' fears as to the undesirability of a cottage load in any district, as the maximum demand for the lighting of cottages could not coincide with the maximum demand on any power station except where cottages only were supplied. The variable charge for different seasons is a valuable feature, and the "insurance collector" idea is novel. I notice that the balance sheet is incomplete, such important features as the cost of wiring and book-keeping being omitted. From the balance sheet it may be inferred that a gross revenue of 4d. per unit was obtainable, and I should like to know if this is the actual revenue per unit delivered to the distributing mains serving this system. Also, can the author state any figures giving the loading per mile of distributor in comparison with figures for ordinary residential lighting.

Mr. W. FENNELL (*in reply*): It is gratifying to find an Mr. Fennell. almost unanimous opinion in favour of extending the benefits of electricity to the artisan, and Mr. Allen goes so

Mr. Fennell. far as to say that it will eventually be demanded. The chief object of my paper is therefore served.

Mr. Chattock's objection to my plan on the grounds that Birmingham is too big, and that its working classes are not all equally honest, will I think disappear if certain districts of a town are avoided. Mere size is no disadvantage but rather the reverse; it costs less per consumer to supervise 10,000 than it does 300, and the profit is shown as so much per consumer. Mr. Chattock in his figures as to maximum demand takes no account of the diversity factor and has probably not noticed the definite statement in the paper to the effect that the figure of 45 watts is the result of careful investigation of the actual number of lamps in use at the time of peak load on the station. Mr. Chattock's suggestion that the figure might be 90 watts is therefore contradicted by the facts. I would go further than Mr. Chattock and say that the consumer's individual maximum demand is not merely 60 per cent but is 100 per cent of the connections, but it occurs at "off peak" times. It would be useless to install a current limiter for a 3-lamp installation. One must allow that at times all the lamps will be required, say on Sunday evenings and Bank Holidays. The habit of Sunday and holiday visiting helps to fill up the load on the power station on the days of least demand. I cannot see how the maximum demand at the time of peak load on the station could be more in an industrial district than what I have allowed. It would be more in a residential area, no doubt, but the figures given are confined to a district having the heaviest peak load between 4 and 5.30 p.m.

With regard to the number of units per annum per house, there are no figures available, but this figure is not of very great importance because, if doubled, it only adds 3s. per annum to the cost. The low running cost (0·35d. per unit) allows the meter to be dispensed with, simply because the interest, etc., charges on a meter exceed the value of the electricity which would be saved if it were used as a check on waste. If the running cost were 1d. per unit the meter could not be dispensed with. There is to my mind no difficulty in keeping the unit consumption down to something like 100 units per annum, if there is the same amount of supervision exercised as that adopted by Water Companies under exactly similar circumstances, viz. to keep waste down to such a figure that it does not pay to charge on a meter basis.

There have been no serious difficulties in securing wayleaves for the looped services. The tenants want the light, and it is to the interest of landlords to let them have it, because it reduces the cost of whitewashing and papering. In the only case that I can remember where a landlord objected, most of the tenants threatened to leave.

Mr. Allen and others stated that I had not gone far enough because no provision was made for heating, etc. This was welcome and unexpected criticism, as I had feared condemnation for going so far; it lends support to my case. I gave reasons in the paper (the always-burning fire providing all the heat required) why in Wednesbury there was no heating demand in this class of house. I agree that if we are to cater for heating, a meter must be used, and I have no doubt that in flats where there is a difficulty in delivering and storing coal, or in districts where coal is dear, something may be done in this direction. The framing of systems of charging, like all other details of management, should be based on a careful study of local conditions and local human nature. The conditions in "coal districts" will be, for some years at least, as described in the paper, but when a consumer wants a supply for heating he can have it as a separate supply through a "cheap" meter. Why go to the expense of installing 300 meters because 30 consumers may want a flat-iron or grill? Mr. Fennell.

The slot meter has failed in most places because it does not fit in with human nature. It gives the consumer an exaggerated idea of cost—the money found in the meter never amounts to anything like the amount that the consumer imagines has been supplied. It produces less revenue, only 6s. 6d. per lamp against 10s. 10d. with the rental system. Consumers were hard to get and to keep with slot meters, but they are easy to obtain with this system because, I believe, money is scarce from Tuesday to Friday. The capital and maintenance costs of slot meters made their use unprofitable. I cannot agree that it would be wise to charge even 6d. each for renewal lamps. Difficulties would arise due to changes of tenancy. It must be remembered that the success of the rental system is due to the certainty of the charges—the housewife knows exactly how much money to leave out for the collector; there are no extras; nothing to pay for wiring, lamps, and repairs. Compare this with a weekly meter reading, with disputes as to the amount used, a meter being generally assumed to be an inaccurate instrument. Remove even one of the above characteristics and the rental system no longer suits the people, and becomes unpopular, book-keeping becomes heavy and involved, and collection is more expensive. With regard to Mr. Holden's suggestion that we cannot afford to give units away however cheap they may be, I must remind him that apart from the actual cost of the meter being more than the possible saving of electrical energy by its use, we have to remember that a non-technical collector works the business easily at present—a meter reader and accurate reckoner of accounts is required for a weekly meter system.

Several speakers thought the wall-plug switch to be dangerous to children. I omitted to state in the paper that it is fixed 5 ft. or 6 ft. from the ground. I cannot see that a 5-ampere plug is unsuitable for breaking half an ampere, or that it is as dangerous as when used in its usual position on a skirting-board where children can play with it. It is satisfactory to hear from wiring contractors that the allowance for wiring is ample, and it is pleasing to hear from Mr. Milns that too much has been allowed for lamp renewals. I wished to be on the safe side, but I agree that lamps will last longer and will soon cost less. I agree that 4 years is too short a period for writing off the cost of wiring. Those engineers who can obtain 7- or 10-year loans will obtain a better result in the early years than that shown in the paper. I think that the twin-flexible surface system has not sufficient mechanical strength for these houses, and I would mention that in many cases the premises are not very clean. Several applications have been refused for this reason. The lead-covered twin system is the most suitable.

With regard to Dr. Railing's suggestion to use a metal-filament lamp of low candle-power in the bedroom instead of a carbon lamp, this has been considered, and it might

Mr. Fennell. reduce the risk of consumers using the bedroom lamp as a night-light. This is the one practical difficulty which has arisen, and there are at least five ways of dealing with it: (1) To forbid it under penalty of removing the bedroom light. (2) To provide a time switch to cut off at midnight. (3) To provide a metal-filament lamp which will be uncomfortable. (4) To provide a turn-down lamp and allow it to be used as a night-light. (5) To provide a pear-switch at the bed. The first-mentioned policy is being adopted in Wednesbury with fairly good results, as the threat of disconnection raises visions of a return to the bad old days of candles or cheap oil-lamps. In my opinion the provision of a pear switch at the bed would entirely remove this trouble.

With regard to the suggestion made by Dr. Railing that the landlord might collect, we have purposely avoided this. We often get paid in preference to the landlord—it is easier to pay 5d. or 10d. than it is 3s. or 4s. By putting the two things together the electricity arrears would at best increase largely and there would be a risk of the landlord claiming payments on account as being for his rent and not for the electricity. I am pleased to find that Dr. Railing, who has had experience of rental systems, confirms all the important principles on which I based the system for Wednesbury.

Replying to Mr. Foster, I could not add the cost of wiring before arriving at the profit because every one has his own idea as to the number of years to be allowed for writing off this cost.

Cost of book-keeping is not omitted—it is included in the collector's commission, to the extent of almost nine-tenths, and the remaining one-tenth is included in the £7 per kilowatt of maximum demand, which covers all the station distribution, clerical office, and capital charges (excluding wiring). I think Mr. Foster is wrong in asking for the revenue per unit, because it means nothing when given. Electrical energy does not "cost so much per unit," and that is the whole basis of the system. The loading of the distributors is so small as to be practically negligible. If there were one consumer for every 5 yards, the loading would be under 40 kw. per mile if all the lamps were alight at once.

Replying to Mr. Holden as to the method of disconnection, the fuses are removed and the three pendants are taken down, being used for the next consumer connected.

DISCUSSION ON

"REACTANCE AND REACTANCE COILS IN POWER CIRCUITS." *

NEWCASTLE LOCAL SECTION, 26TH AND 30TH JANUARY, 1914.

Mr. Hunter. Mr. P. V. HUNTER: At the commencement of the paper it is stated that recent developments in the design of generators have tended to reduce the self-induction of the armature, but my experience is that the most recent practice is to increase the self-induction of the armature, and in fact designers have endeavoured during the last year or two to increase the self-induction without sacrificing mechanical rigidity. The author calculates the short-circuit current of a power-supply system having a capacity of 50,000 kw. of generating plant to be 120,000 amperes. It would, I think, have been of more interest if the voltage of the system had also been given. The use of reactance in busbar section switches is proposed in power stations, and there are arguments in favour of its use in this position, but there is an important argument to the contrary, namely, that on an ordinary transmission system the busbar sections are also connected together, through the transmission system, in parallel with the busbar section switches. A busbar reactance having a substantial difference of pressure across its terminals when loaded would therefore shunt a somewhat heavy current through those feeders connected in parallel with it. If, to meet this objection, the use of such parallel feeders is avoided, a large network then becomes an uneconomical aggregation of small networks, and the cost of it would be prohibitive. The author suggests the use of reactance coils in feeder circuits, but I must say that my experience is entirely opposed to their use in such a manner; in fact one of the transmission difficulties in this district is the reduction, due to the reactive drop, of the effective transmission distance of overhead lines compared with that of cables. This has necessitated considerable expenditure in regulating apparatus. Any proposal therefore to add reactance to the underground cables would be regarded with distinct disapproval. Reference is made on page 257 to reactance and regulation, but I am unable to agree that voltage variation is unimportant; according to my experience it is a matter of some difficulty to keep the pressure at the consumer's terminals reasonably constant without incurring expenditure in special voltage-regulating apparatus. On systems operating with a lagging power factor the use of reactance would involve a substantial increase in the cost of the transmission system. I have not found it necessary to use a special reactance in generators. It will generally be found convenient to step up to a higher voltage through a transformer, and it is very easy to incorporate a reasonable amount of reactance in transformers without additional expense. The author gives a very apt description of the way in which high-frequency surges flowing into a transformer break like waves against a breakwater, and he recommends the use of reactance coils to protect the transformer; it seems to me, however, that the same purpose is served by specially insulating the end turns of the transformer. The author states that up to recent years consulting engineers have

* Paper by Mr. E. P. Hollis (see p. 254).

Hunter. specified transformers with low reactance, but that they now specify high reactance. While this may be true so far as his experience goes, it is certainly not the policy of the firm with which I am connected. Reference is also made in the paper to the methods of obtaining high reactance in transformers in order to reduce the short-circuit current and consequent mechanical damage. I consider such reactance to be both objectionable and unnecessary in power transformers, as they can be constructed without materially increased cost to withstand short-circuit currents of 40 times the full-load current. This corresponds to a full-load impedance of $2\frac{1}{2}$ per cent, and a regulation on ordinary power factors of the order of 2 per cent, which may be considered satisfactory. I gather that the author's calculations apply to the sandwich-coil form of transformer and not to the concentric form which is, if anything, the more commonly used type. The point to which the author draws attention respecting the weakness of using iron in the leakage paths is distinctly good. There is generally, however, an air-gap in these leakage paths and the tendency to saturation is not as great as one would expect. It is very fortunate that in this country the troubles described on pages 258 and 259 do not arise. It must be a very difficult matter to transmit energy over such long lines and maintain reasonable voltage at the far end. The suggestions made by the author to overcome these troubles offer technically a real solution, but the adjustable reactance would, I fear, present considerable difficulty. However, I have no doubt that some compromise can be obtained which would be an improvement on present arrangements. The author's suggestion for obtaining a constant-potential transmission system is most interesting, but the amount of costly synchronous plant which would have to be installed would be prohibitive. On page 260 the author suggests the use of reactance coils to protect the end turns of high-tension induction motors. I would suggest the use of a transformer. I think that the stator of a motor is not the place for a high-tension winding. Such a winding becomes uneconomical on small motors and there is increased probability of shock and breakdown. The suggestion of using a continuous-current coil for superimposing a continuous flux on a reactance in order to render the reactance adjustable is most interesting, but it seems to me that the graph of the alternating current through the reactance coil would have dissimilar shapes for each half of the wave.

Gregory. Mr. R. W. Gregory: I hope that the author will not persuade anybody to fit to power-station busbars reactance coils such as those illustrated. They may be of use in other places, but I think it should be an axiom among switchgear designers and engineers to keep power-station busbars as simple as possible and free from apparatus of any sort.

[And]rews. Mr. J. R. Andrews: I should like to point out that overhead lines are not "loaded" in England, although the practice is very prevalent in America, where it is claimed that there is a great saving in copper by using loading coils. In the case of overhead wires conversation is possible over a distance of about 1,600 miles, as against about 36 miles for standard underground cables; loading coils are used, however, in the latter case to increase the distance, series loading being found the better arrangement. In international telephone cables the following three methods of increasing the speaking mileage are used: (1) By using heavy copper conductors with large interspaces, whereby the capacity is reduced; (2) by using an additional wire for continuous loading; and (3) by interspersing telephone coils as antidotes to the capacity effects. Mr. Andrews.

Mr. J. Schuil: In America inductance coils are largely used by the various Edison companies. The fact that one of their engineers is the designer of the porcelain-clad type may have something to do with this. There is, however, no question but that such coils are valuable. The engineers of the Washington power station told me that owing to short-circuits one of the generators had been burnt out twice, laying it off 8 months altogether. Since the introduction of the inductances, no breakdowns had occurred on the machines—a valuable asset where the station is fully loaded. Mr. Schuil.

Mr. J. R. Beard: While I agree with the author as to the advantages of additional internal reactance in alternators and transformers, I think he views the use of special external reactances in somewhat too favourable a light. As an external reactance coil is an additional potential source of breakdown, its use requires justification, and glancing at the various uses which the author proposes for it, I do not see much justification for its application to the cases of alternators, transformers, or feeders, except in special circumstances in the last-mentioned case. As regards alternators, manufacturers can readily build machines with sufficient internal reactance to limit the maximum momentary peak of the short-circuit current to less than 12 times the R.M.S. current at normal load, and, in addition, on large systems there is the reactance of the step-up transformers to be considered. Apart from other disadvantages, I should imagine that if a part of the reactance were external to the machine it would be more costly, particularly if account be taken of the additional space occupied, and I should therefore be interested if the author could give some actual comparative figures on this point. It has been proved by very extensive short-circuit tests carried out in this district on transformers made by several firms that when designed on ordinary commercial lines with a regulation of say 2 or 3 per cent at 0·8 power factor, transformers can be constructed so that they will stand up without damage to a "dead" short-circuit on the secondary with full terminal voltage maintained on the primary. Turning to the question of the use of reactance coils in high-tension feeders, it is evident that if they were used indiscriminately on say a 20,000-volt system the effect for all practical purposes would be to reduce the 20,000-volt system to the equivalent of say an 11,000-volt one. The author of course does not propose such indiscriminate use, but I gather that he favours the use of such coils for all feeders from a power station, since he states that "reactance coils in feeder circuits naturally follow for limiting the power on short-circuit." I cannot agree with this as applied to the general case of main feeders to a large distribution system. As it is uneconomical to tap a main feeder near to the power station such feeders are usually of considerable length, and thus they have sufficient impedance to prevent excessive current flowing into a short-circuit at their far end. Further, a breakdown on the feeder itself is scarcely more probable than would Mr. Beard.

Mr. Beard. be a breakdown in the reactance coils, and in any case the switch at the power-station end must be designed for the latter contingency. For short high-tension feeders to sub-stations near to the power station the case is different, and I agree with the author that reactance coils should be used if the power station is large. The drop in pressure which they cause does not matter as there is practically no drop in the feeders. They also have the very great advantage that not only does the effect of a short-circuit on the sub-station or on the consumer's apparatus prove to be a less severe strain on the system, but in addition ordinary sub-station switchgear can be installed by the supply authority and the consumer can safely use standard commercial switchgear; whereas if no means were taken to limit the short-circuit current, the supply authority would have to install power-station type of switchgear at the sub-station, and the consumer would be similarly obliged to install at considerable extra expense special switchgear designed for the most severe conditions. The author also recommends reactance coils for sectioning extensive high-tension networks. On many systems this may be done with advantage, but in this district the conditions are rather special as, owing to the large number of waste-heat stations running at practically constant output, the power is transmitted in entirely different ways at different times. Consequently whatever sectioning points are arranged for there will be heavy currents flowing through them at one time or another, and, if reactance coils were installed, large voltage drops would be produced, which would necessitate further additions to the already complicated arrangements that are required on extensive systems for regulating the voltage. With regard to the descriptions that are given of actual constructions for reactance coils, I should be glad if the author could inform me whether any trouble has been experienced arising from the effect of the large stray fields in heating surrounding ironwork such as girders, etc. A well-known type of reactance coil which is not described is designed with a core partly of iron and partly of wood, the arrangement being such that no external field is produced. This type of construction has the further advantage that it enables the coil to be oil-immersed in a standard metal tank.

Mr. Baxter. Mr. W. BAXTER: This paper would lead one to believe that there is no electrical trouble which inductance coils cannot cure, but the fact that these coils are not used to any extent on the local supply systems seems to point to the possibility that there may be other ways of obviating the difficulties referred to. In a recent case where two large fan motors at a colliery gave continual trouble on a 3,000-volt system due to "potential front," the trouble was entirely removed by arranging high-resistance nets in the main oil switches, with contacts so designed that the high resistances were momentarily connected in series with the stator winding. Such an arrangement would be much cheaper than any type of external reactance, as all that is necessary is to deepen the tanks slightly, and in fact the cost would not exceed two or three pounds.

Mr. Philipp. Mr. R. C. PHILIPP: For the paralleling of transformers of different regulation, capacity, or voltage, the use of choke coils is the simplest arrangement. An ingenious way of paralleling two transformers of different voltages is to connect them by a choke coil and to take the supply from a tapping off some point in the choke coil—this point to be nearer the transformer of greater voltage. Although the use of reactance coils for transformers of different pressures is only required in an emergency, it is useful to bear it in mind.

Mr. Vesey Brown. Mr. C. S. VESEY BROWN: In the discussion the following terms have been used:—reactance, inductance, impedance, choking coils, and choking reactance. I should be glad if the author would state which is the correct term to be employed. The value of the use of reactance coils in connection with generators has been questioned. My experience leads me to insert them wherever possible. A generator is a very expensive piece of machinery to repair, and so after having experienced the necessity of having to burn out a fault I prefer to use reactance coils. The question of their use in other directions is perhaps to be decided by experience, but so far as generators are concerned I am sure that in future a reactance or spring-loaded buffer will be necessary—at any rate when it becomes a question of protecting a plant of more than 10,000 kw. capacity.

Mr. Wright. Mr. G. N. WRIGHT: I should like to ask the author a few questions of a practical nature. He speaks of the advantage of added reactance in transformers. What are the disadvantages? He also mentioned that Mr. Hobart suggested the use of fuses in the field-coil circuits in cases of breakdown. On account of the high voltage developed when a circuit is broken suddenly, would this not lead to trouble? Would it be practicable to put a non-inductive resistance across the field-winding, or would this have to be too high to suit running conditions to be of use under breakdown conditions? On page 256 the author refers to the generators being connected to a neutral busbar earthed through a resistance or reactance coil. The usual practice would appear to be to earth only one generator, although if the machines were connected to a neutral busbar they would then share the short-circuit current. Does the author favour this latter method? Would not reactance coils introduced into circuit-breakers have to be very strongly built, since when the switch is opening under fault conditions the current has already started at a high value and has to be reduced by the reactance. In such a case the reactance would be subjected to greater stresses than if it were already in the circuit. With reference to the statement that operating engineers have gone so far as to insert reactance coils between the generator and the busbars, so as to be able to switch in a machine when it is 180 degrees out of phase, I am of opinion that this seems to be going too far, as the amount of reactance that would have to be inserted would be much higher than the author would appear to consider necessary for ordinary operating conditions. The point raised near the top of page 259, that the trouble with the rise of pressure could be overcome by reducing the size of the conductors near the receiving end so that it is just above the critical value for corona loss, is very interesting. What percentage length of the line would have to be reduced to that diameter for safety? At the top of page 260 it is mentioned that the reactance coils might be called upon to carry currents for many minutes. I should have thought that if the fault were on a cable protected on the Merz-Price system it would not be likely to last so long.

Mr. P. S. THOMPSON: When certain portions of this paper were written I think the author did not give quite as much consideration as he might have done to the perfection of protective gear, which does what the author claims for his reactances, namely, to make faults local affairs. As previous speakers have remarked, the quickness of mechanical operation cannot altogether be relied on, and no doubt the author believes in tackling the matter before it becomes serious enough to necessitate the breaking of heavy currents. What would be the effect of the use of a number of these reactances on the power factor generally of the system? In the case of a short-circuit at a very low power factor an oil switch may have to contend with a condition which at zero current in the ordinary way tends to restore the circuit just when the break should occur, and I wonder what effect the reactances would have on that condition, *e.g.* whether it would make it easier for the oil switch or not. I was rather surprised to see the statement that it was immaterial whether steam was on the generators or not in the case of a short-circuit. We all realize that an immense amount of energy is stored up in the rotating parts. Unless steam is behind these parts I am afraid the frequency would after the first short interval of time decrease sufficiently to throw some of the synchronous machinery out of step. However, no doubt the author's statement is borne out by fact, as he refers to tests at Fisk-street power station. In the paragraph on page 257 headed "Reactance and Regulation" he says, "Increased reactance in a circuit with a lagging power factor naturally adversely affects the regulation. But this is a matter which is not so important as it was some years ago." Why?

Mr. W. D. LOVELL: In connection with the regulation of alternators, would 20 per cent be a fair figure? As regards Mr. Longman's statement with reference to reactance coils for circuit-breakers, I think the general practice for circuit-breakers of high capacity is to insert two reactance coils in series, in parallel with the main contacts, there being two sets of two contacts per pole, one set being employed for the main contacts, the other set for the reactance contacts. Have electrostatic condensers been used for increasing the power factor by connecting them across the terminals of large motors? Instead of placing reactance coils in circuit between the transformer and the slip-rings of a rotary converter to obtain voltage regulation (5 to 10 per cent) on the converter by varying the field strength, why not design the transformer so that it has a high reactance and thus do away with the coils and still have the same result?

Mr. C. O. BRETTELLE: I suppose the principal items of this paper would come under the heading of insurance of plant. It would be interesting to see some kind of curve showing the relation between the amount of damage likely to be done without these choke coils and the amount of saving to be effected by their installation. One would have to take into consideration the cost of the additional floor space needed by all the reactances, the use of which is suggested in the paper. In regard to the unsteady running of generators in parallel, could not the steadying effect be obtained from the mechanical end by adjusting the governors, and by making these less sensitive, eliminating the necessity for a reactance coil?

Mr. R. M. LONGMAN: In looking up one or two papers read recently on protective devices for high-tension transmission circuits, I was surprised to find how little attention has been paid to reactance methods. In Mr. Peck's paper of 1908* a slight reference is made, but chiefly in regard to choke coils for protecting transformers, and one is shown in the form of a flat spiral of which the dimensions are not stated. Mr. Hadley† has described the type of switches used at Rosherville. He says that a two-movement reactance switch is being installed. Does he mean that the reactance coils are actually in the switch tanks? I should like to know what size these reactances would have to be in an 80,000-volt circuit when there is a total capacity of 150,000 kw. connected. Mr. Hadley also states that 6 per cent reactances are being installed between the machines and their transformers, the latest practice being to design both generators and transformers with large internal reactances. That figure (6 per cent) is less than the 15 per cent mentioned by Mr. Hollis. I agree with the author that on a short-circuit not only the maximum short-circuit current of the generators has to be considered but also the inertia of the apparatus connected to the system, and especially that of rotating plant, such as motor-generators and rotary converters, which is connected direct to the line. Of course the time in question is perhaps 1/100 second, or even less than that. I saw a few time tests made on some switches for South Africa, and the total time from the instant at which the switch commenced to open to the final opening of the circuit was 0·65 second, including the mechanical operation and the actual interruption. The damage is usually done in half a period or at most 2 periods. In one case where several stations are running in parallel, with an interconnector 20 miles long between the two groups, a pulsating effect has been noticed. Would reactance coils have any steadying effect? I believe that the pulsation is really due to the difference between the governors on the various prime-movers. The various inductances on a system of this nature cannot be calculated. Another effect noticed has been the breakdown between the turns on regulators owing to the charging of electrolytic arresters. The frequency with which we are dealing is probably about 50,000, and it is important to know what should be done in such a case. Another interesting point has been noticed in the case of two systems running in parallel connected by two interconnectors; on one of these being opened at a synchronizing point the synchroscope pointer was observed to be oscillating, and it finally rotated—the other switch had just tripped. The oscillation of the pointer indicated hunting and instability. The problem of keeping two or three large stations in parallel is most difficult and intricate. Of course it will have to be solved, and anything that will increase our knowledge of such problems will be most helpful. In regard to the adjustable reactance referred to on page 260, I suppose the reference is to Dr. Coales' experiments some years ago, which unfortunately were not carried as far as they might have been. At the top of the same page where it is stated that reactance coils will be called upon to carry the current for many minutes,

* J. S. PECK. Protective devices for high-tension transmission circuits. *Journal I.E.E.*, vol. 40, p. 498, 1908.

† A. E. HADLEY. Power supply on the Rand. *Journal I.E.E.*, vol. 51, p. 2, 1913.

Mr. Longman.

should not this be seconds? Would the author recommend the insertion of reactance coils to steady a load that is rapidly and violently fluctuating? Referring to reactance and third harmonic currents, I have often wondered why resistances are so much favoured, as their cost and upkeep is very heavy. Of course the heating caused by harmonic currents may not be of great importance, but what about the magnetic effect on the machines? Is not this more important? With Mr. Paton, I think the 15 per cent mentioned near the top of page 257 seems rather large. On page 256 in regard to reactance circuit-breakers in parallel, to install them in series would appear to be a better arrangement, otherwise one switch is almost sure to operate sooner than the other, leaving the final breaking to a single switch. Certainly the proper thing to do in the case of a very large power station is to divide the busbars into sections and to insert reactance coils and switches between each section, so that under normal conditions there would be very little current flowing through these reactance coils, and the effect of a fault would be restricted to one section.

Mr. Marshall.

Mr. A. H. W. MARSHALL: Reactance has in the past been looked upon as being rather objectionable for most commercial purposes: now we are told that in every respect it is a very good thing. The only comment which I have to make is that we can have too much of a good thing. I think we should not at once put reactance to all the many uses that the author suggests, and I believe that he himself would not advocate that being done. In regard to the effect of short-circuits on machines, there is no doubt that the field current does rise to a high value and that the turns of the field winding are liable to be short-circuited if they are not well insulated. For this reason rotors with completely insulated windings are less likely to give trouble than those having bare-strip end connections. The figure of 120,000 amperes which the author mentions on page 255 as the short-circuit current of a big station would, I suppose, only exist for a fraction of a second, the steady value of the current being only about $\frac{1}{5}$ or $\frac{1}{6}$ of this; and the number of kilovolt-amperes that the switch would have to break would not be so large as that mentioned. In regard to the stability of power systems, it seems to me that the insertion of reactance coils between generating stations would, as a rule, have the opposite effect to that which the author states, especially where the stations are joined by long overhead lines. Taking the case which Mr. Longman quotes of two systems each containing several stations and a big power load, there is no doubt but that the conditions of parallel operation become worse when either the resistance or reactance of the connecting mains is increased. The two systems are interconnected by a cable and an overhead line in parallel; with the cable switched out there is a greater tendency for the current to surge, and it is this which brings about the peculiar synchronizing effect to which Mr. Longman draws attention. I consider the most important use of reactance coils to be in sectionalizing the busbars of very large stations. Bearing in mind the size of generating stations in this country and the fact that the larger trunk mains take the form of overhead lines, that seems to me to be at present the only place where reactance coils can be profitably employed. It is possible that in special cases larger feeders (especially if these consist of underground cables) may be advantageously fitted with reactance coils, but the question of regulation has always to be borne in mind, and it is this which has to be taken into account when considering what limit shall be placed on the short-circuit currents. As an instance of the desirability of not increasing the reactance of feeders, I might mention that split circuits are used on some of the largest overhead lines in this district. I should like to ask the author if he knows of any form of resistance which has been successfully used for choking purposes. In regard to the operation of synchronizing machines, in my opinion the extra complication involved by the use of reactance is undesirable. It is found in everyday practice that ordinary synchronizing can be carried out quite well by anybody who has had a little experience, and also that there is very little danger.

Mr. Paton.

Mr. A. M. PATON: The paper reminds me of a few sentences contained in the preface by Dr. Steinmetz to one of his latest books, to the effect that the future progress in electrical engineering is dependent upon the understanding and control of what he terms "transient electric phenomena"—some of which are discussed in this paper. Incidentally, I should have liked to see in the paper some reference to the genius that Dr. Steinmetz has shown in analysing the very complex transient phenomena which occur in practice. I was interested in the author's statement that on short-circuiting an alternator eddy-current effects have been recorded equal to 2·4 times the armature reaction. The larger the ratio of the armature reaction to the leakage reactance the higher is the instantaneous value of the short-circuit current; consequently, if I understand the author's statement correctly, the eddy currents may, after they have begun to take effect, reduce the short-circuit current to approximately one-half of its probable value if there were no eddy currents. Could the author indicate under what circumstances this phenomenon might be expected to occur, and in his opinion would there be any practical value in seeking to reproduce the conditions so as to bring the short-circuit current as rapidly as possible to its permanent value, in other words "damp" it? With reference to the external reactance sometimes found necessary for operating alternators in parallel, I believe that the leakage reactance of a modern turbo-alternator is of the order of from 2 to 3 per cent, and that the internal resistance is 1 per cent plus the resistance of the cables connecting the machine to the busbars. From these figures it is quite clear that in order to bring the ratio of the reactance to the resistance up to the 3 or 4 to 1 mentioned by the author, a considerable amount of reactance must be added. The figures mentioned for the additional reactance, namely, 15 per cent and 20 per cent, are considerably higher than those that I have noticed elsewhere, which I think are mostly of the order of from 5 to 10 per cent and which check with those mentioned later in the paper. The latter figures limit the short-circuit current to between 10 and 15 times its full-load value. Are these large reactances mentioned by the author used on many systems? With regard to the suggestion contained near the bottom of page 257, I should like to ask the author whether choke coils have not been successfully used for years to protect transformers from line disturbances of high frequency. I should also like to know whether the author believes that shunted induct-

ance will be necessary on transmission lines in this country. The conditions here are fundamentally different from those in the United States, for two reasons: First, the length of transmission lines in this country will not be such as to necessitate anything like the high voltages which are necessary in America; and secondly, in this North-East district, which is likely to continue to possess the most important electrical transmission system in this country, we are not troubled, or likely to be troubled, with very light loads and the excessive rises of pressure due to the effect of the charging currents at such times.

Mr. E. P. HOLLIS (*in reply*): While there have been in several quarters justifiable reservations, it is evident from the discussion that current-limiting reactances are accepted as offering a solution of a number of power-station problems.

Mr. Hunter has misconstrued one of my remarks with regard to recent developments in the amount of self-induction of generator armatures. That remark was intended to summarize the developments since the introduction of low-speed alternators. In the early 100-cycle machines the armature reaction was less than the self-induction, and the transient short-circuit current was little less than the steady short-circuit current. With the advent of 50-cycle systems it was possible to double the pole pitch, thereby allowing the armature reaction to be doubled, while the self-induction was reduced by subdividing the conductor in a number of slots per pole. In such machines the armature reaction and the self-induction were nearly equal, so that the transient short-circuit current was of the order of twice the steady value. Then came 25-cycle systems, and again the pole pitch and armature reaction were increased. The adoption of higher peripheral speeds in the steam turbo-alternator still further increased the pole pitch and with it the permissible armature reaction, whilst the self-induction remained the same. A large armature reaction necessitated higher field excitation and was followed by developments which made it imperative to design the turbine on more economical lines, with the result that deeper armature slots and higher flux densities were resorted to. The former resulted in an increase in the armature reaction and the latter in a decrease in the self-induction, with the results that have been noted in the paper. That designers have endeavoured to increase the self-induction of modern machines, as Mr. Hunter remarks, is quite true, and is a phase of the question, which is discussed throughout the paper, of a general increase of the self-induction. The voltage asked for by Mr. Hunter is 6,600. The figure for the current was given as an example of the heavy currents that may occur on short-circuit on a typical system.

Together with Mr. Beard, Mr. Gregory, and others, Mr. Hunter raises the question of the shunting of busbar sectioning reactances by the feeder system, and I agree that this is an important matter. Indeed, the introduction of busbar reactances makes it necessary completely to revise the usual methods of laying out busbars, quite apart from whether the reactance would or would not be shunted by the feeder system. The "substantial difference of pressure" to which Mr. Hunter refers would only occur across the terminals of the reactance on short-circuit or when one busbar section was so heavily overloaded that it became necessary to draw a supply from another section of the station to cope with the load. I think that Mr. Hunter's fears will not be realized in the majority of cases. Where a pair of feeders on different busbar sections were connected together just outside a power station it would of course be futile to insert busbar reactances. Where, however, the feeders are long and there is a considerable feeder reactance between the two sections of the busbars, the efficiency of the reactances would not materially be interfered with. I cannot agree with Mr. Hunter that the installation of reactances in the power station would largely increase the cost of the transmission system, as the additional lagging current in the cables would be very small indeed. Mr. Hunter says that he does not use special reactances, since he can obtain sufficient reactance in the transformers without additional expense. The reactance coils are, however, intended to protect the generator, and what would be the use of reactance in the transformer for protecting the generator in the event of a short-circuit on the primary of the transformer itself—quite a likely event?

The same purpose is served by insulating the end-turns of transformers as by the use of a special protecting coil, as Mr. Hunter remarks; but it is all a question of advisability, and many engineers are of opinion that the protection should be afforded to the transformer outside, where in the event of a breakdown on the protective device—which after all is the more likely part to fail during the surge—repairs can easily be effected.

The suggestion made by Mr. Hunter that the amount of costly synchronous plant that would have to be installed would prohibit the use of a constant-potential system, is not in my opinion justified. It is the increased expenditure on and the smaller capacity of the line due to reactance drop, which are referred to earlier in Mr. Hunter's remarks, that the constant-potential transmission system is intended to overcome. Transmission lines are very costly, and if the capacity of a transmission line can be increased from 20 to 30 per cent, as it often can be by the use of synchronous machinery, and, if necessary, more reactance, it is frequently possible to show that the installation of synchronous plant is a good paying proposition. I do not, as Mr. Hunter remarks, suggest that reactance coils should be used to protect the end-turns of high-tension induction motors. I merely recorded the fact that they are largely used, and, indeed, are demanded of consumers by some large supply authorities. Most people will agree with Mr. Hunter that the transformer and a low-tension induction motor is the better alternative; but I am sure that Mr. Hunter will know how difficult it is to persuade a customer to go in for the more expensive scheme.

Mr. Gregory deprecates the use of busbar reactances as an additional source of danger and complication. I think this is a matter at which one should be careful to look in its true perspective. In all modern power stations busbars are sectionalized through switches, and it cannot properly be called a complication to insert in the leads such a simple thing as a current-limiting reactance. I doubt whether Mr. Gregory would trouble himself much about the inclusion of another current transformer, which has a far lower factor of safety than a current-limiting reactance.

While objecting to external reactance Mr. Beard is

Mr. Hollis. quite willing to approve of internal reactance. To that I can only repeat what I said in the paper, that internal reactance does not protect the plant against internal short-circuit when there will be a large influx of power from external sources. This may irretrievably wreck the plant, otherwise, the breakdown being protected from a rush of current from the busbars might have far less serious consequences and the plant could easily be repaired. The amount of room taken up by current-limiting reactances depends entirely upon the type used. The open type certainly takes up considerable space, but the porcelain-clad type is very compact, and the increase in the amount of room which it is necessary to provide becomes negligible. In large power stations it has to be remembered that the switchgear is entirely removed from the engine-room, and that the designer is not so pressed for room as he was previously, so that it is beside the point to lay stress on the extra amount of room taken by reactances.

Mr. Beard inquires as to the effect of a large stray field on surrounding metal-work. It has been found that in a proper installation the effect is negligible. Naturally it is desirable to keep the coils as far away as possible from metal-work, and in practice it is not found difficult to do this satisfactorily.

Mr. Baxter mentions the use of resistance circuit-breakers. Resistance has, however, given place to reactance, owing to the fact that the resistance absorbed a large amount of power and was frequently burnt out.

Mr. Philipp refers to what he calls a new use for reactance coils. In his scheme, however, he is not using reactance coils but auto-transformers.

I am glad to find that the experiences of Mr. Vesey Brown and Mr. Schuil have led them to have confidence in reactance coils. Mr. Vesey Brown's remarks are very much to the point. Money spent on reactance coils is in the nature of insurance, and in these days of penalties a complete failure of supply or the inconvenience of one or two burnt-out generators is a thing to be avoided. I thoroughly agree with Mr. Brown that the number of terms which are used in connection with reactance is very confusing. Still, I do not think there is any chance of reducing the number. In fact I might have used many more. I have, for instance, avoided "capacitance" and others which find their way into technical literature in America. Inductance is of course the easiest thing to talk about, because one does know fairly well what is meant by and what is included in the term "inductance." Then the effect of inductance on a current varies with the frequency, and so we speak of "reactance"; but reactance includes quite a lot of things. The "synchronous reactance" of a generator includes eddy-current effects, armature reaction, the transformer action of the armature current upon the field winding during short-circuit, and so on; while if the resistance were increased due to transient effects it would be difficult to dissociate it from the general term "synchronous reactance." "Impedance" of course includes resistance and capacity effects and is a comprehensive term which includes the whole of the effects that tend to limit or increase the flow of current in a circuit.

In reply to Mr. Wright the disadvantages of adding reactance to transformers are worse regulation, increased losses (especially eddy-current losses), and reduced efficiency. These disadvantages are of course not very Mr. Hollis. serious and are entirely overshadowed by the advantages that are obtainable in certain instances by adding a reasonable amount of reactance. I disposed of the suggestion that fuses might be used in field-coil circuits to blow at about twice the full-load current by pointing out that the rise in pressure in the field due to the breaking of the current might be the cause of serious damage in the field coils. I cannot see that a non-inductive resistance will serve any useful purpose. If it were low it would be a source of considerable inefficiency owing to the amount of current that it shunts, and if it were made high it would not be of very much use.

As I pointed out in the paper, when the star points of all the generators running in the station are earthed, they share the short-circuit current between them, whereas if only one point is earthed, that machine is exposed to the full shock of a short-circuit to earth. Connecting all the neutral points to earth has the advantage that the shock per machine is less, but the aggregate flow of current into the short-circuit is greater.

Naturally, as Mr. Wright suggests, any reactances introduced into circuit-breakers would have to be strong, but all reactances can be made extremely strong and with a very high factor of safety indeed. He has misconstrued that part of the paper in which I recorded that reactance coils were used for synchronizing machines. Those coils are of course only inserted temporarily and are short-circuited after the two machines are paralleled.

Where the size of conductors near a sub-station is reduced in order to dispose of a pressure rise occasioned by the leading capacity current of the line flowing over the line reactance, the conductors are only reduced in size for a short distance near the sub-station. As I explained on the blackboard, although there are points of similarity, there is a material difference in the unbalancing of pressure in a two-phase three-wire system due to the reactance of the motor and the rise in pressure due to a leading current flowing over a reactance. In the two-phase three-wire system the reactance E.M.F. on phase A is 90 degrees out of phase with the impressed E.M.F. and therefore falls into step with the impressed E.M.F. on the second phase B. On the other hand, the reactance E.M.F. on the phase B is 90 degrees out of phase with its impressed E.M.F. and 180 degrees out of phase with the impressed E.M.F. on the first phase A. In consequence, the reactance E.M.F. of phase A is added to the impressed E.M.F. of phase B, but the reactance E.M.F. of phase B is subtracted from the impressed E.M.F. of phase A. There is therefore a difference in pressure between the two sides equal to about twice the reactance E.M.F. of one phase.

Together with several others, Mr. Wright does not appreciate my point that a reactance coil may be called upon to carry a current for several minutes, and, like the others, he directs attention to the fact that if the fault were on a cable protected by the Merz-Price system it would not last that time. This, of course, is quite true, but if the fault occurred in a sub-station, as it often does, and the overload relays failed to act—I could point out many cases in which they have failed to act—the reactance coil might be left in circuit many minutes. After a few seconds the load would decrease to the permanent short-

circuit current, and the feeder could be switched out at leisure.

At Mr. Thompson's request I have prepared a diagram (Fig. A) showing how the reactance coils are arranged for a system with two power stations running in parallel. I have assumed that the conditions on such a system are remarkable; that it includes:—

(*a*) short feeders for, say, an electrolytic works where the rushes of current are heavy;

(*b*) a transmission line so long that it becomes necessary to add shunted inductance to reduce the rise in pressure towards the end of the line, and also to increase the efficiency of the line;

(*c*) a line which, owing to the drop in pressure due to the reactance of the line, it has been thought advisable to convert to the constant-potential system;

(*d*) two power stations which are rather far apart and where it has been necessary to introduce reactance on underground cables in order to improve the parallel running of the two power stations in the method that I have described;

(*e*) a number of feeders on which the inherent reactance is adequate for current-limiting purposes in the event of a short-circuit in the sub-station. (No amount of inherent reactance in the feeder can protect the generator in the case of a short-circuit near the power station.)

It should be understood that no attempt has been made to include the internal connections in the power station, which need far more consideration than can be given here.

Mr. Thompson was surprised to see that it was immaterial whether steam was on the generators or not in the case of a short-circuit. I gather from his remarks that he has not quite followed what I said. Steam is only switched off as an experiment in order to ascertain what effect that condition had. Of course the speed of the turbine would decrease rapidly in the case of a short-circuit. Like several other speakers Mr. Thompson has not appreciated the difference between the regulation of a machine from the manufacturer's point of view and the regulation of a system with that same machine controlled by means of a voltage regulator and connected to busbars. The very worst regulating machine could be made to give a good regulation by means of the voltage regulator.

Mr. Lovell inquires whether electrostatic condensers have been used for increasing the power factor. Their use has been suggested, but unfortunately they are too costly, and the leading current which they take cannot be adjusted.

Mr. Longman inquires as to reactance circuit-breakers. In these circuit-breakers the reactance forms part of the device. The amount of reactance that would be used with switches could of course be very high, as the coils are only in circuit for a few moments. How high depends on the rating of the switch, and a 15 per cent reactance could easily be used for this purpose. Beyond this the reduction in current strength is comparatively small. The same speaker compares the figure of 15 per cent suggested by Durgin and Whitehead with the figure of 6 per cent mentioned by Mr. Hadley; but Mr. Hadley's figure was for external reactance, and had to be increased by the amount of internal leakage reactance to the machine and transformer. As that might easily have been 5 or 6 per cent for the generator and 3 per cent for the transformer it is quite clear that the total leakage reactance is brought up to 14 or 15 per cent, so that there is not such a difference between the figures as Mr. Longman suggests. Whether the parallel running of the stations of which Mr. Longman speaks can be improved by means of a reactance depends Mr. Hollis.

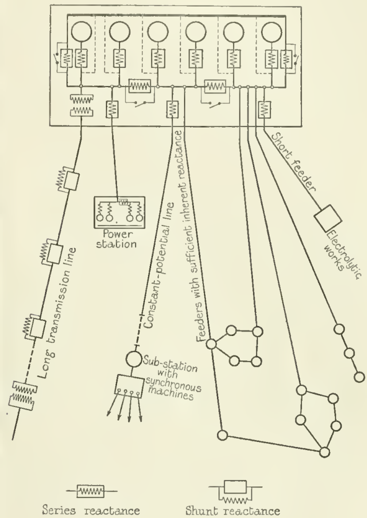

Fig. A.

entirely upon the amount of resistance that is present between the stations. Of course, if the resistance is very high no amount of reactance can improve the parallel running; but if the resistance is fairly low, but still too high to permit of good parallel running, it would be possible to improve the parallel running by the insertion of reactance in the interconnectors.

The fact to which Mr. Longman draws attention, of the breakdown between the turns of regulators due to the charging of electrolytic arresters, is curious, since the electrolytic arrester itself is prescribed for the protection of induction regulators against high-frequency surges. If a generator were connected to a line through an induction regulator, that regulator would take the surges and be exposed to considerable dangers. If, however, it were

Mr. Hollis. shunted by means of an electrolytic arrester, it would be protected from high-frequency discharges. In Mr. Longman's case the high-frequency currents are set up by the charging of the electrolytic arrester itself, and here reactance is the remedy, for a slight inductance in series with the arrester will have an enormous reactance owing to the high frequency of the currents, and it should entirely damp them out.

Mr. Longman inquires as to the advisability of inserting reactance coils to steady a rapidly fluctuating load. I doubt whether a reactance would be of very much use. A reactance coil would of course be limited in size, since it would not do to lower the power factor of the circuit too much, and I am afraid that the largest reactance permissible would only be sufficient to damp down very rapid kicks: such kicks have very little effect upon generators or overload relays with time limits.

Resistances for choking purposes, as mentioned by Mr. Marshall, could not of course be successfully used, as the drop of pressure across them would be large, and it might be that their effect would be to increase the short-circuit power rather than to limit it, but not, of course, the current.* Mr. Hollis.

In answer to Mr. Paton, it would not be possible to use the eddy-current effect in order to damp down the short-circuit. The effect is a product of the short-circuit current itself, but the time lag between the cause of eddy currents and the reaction that they have upon the armature is unfortunately large, and their full effect is felt too late.

In conclusion I should like to join issue with some of those speakers who have suggested that the question of reactance coils for transmission lines has little interest for us in this country owing to the fact that we have no very long transmission lines here. In my opinion such speakers are taking too parochial a view of the whole question. In this country we are supplying electrical machinery for all parts of the world, and it is our duty to investigate those questions which would enable us to add to our export trade.

* E. P. Hollis. The variation of power with resistance in an alternating-current circuit. *Electrical Engineer*, vol. 35, p. 345, 1905, and *Science Abstracts*, vol. 8, B, No. 588, 1905.

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TERMS AND DEFINITIONS PROVISIONALLY APPROVED BY THE BRITISH ELECTROTECHNICAL COMMITTEE.

REVISED MARCH, 1914.

Soon after the formation of the International Electrotechnical Commission, the British National Committee appointed a Nomenclature Committee. This Committee proceeded to consider and draft definitions of the electrotechnical terms in current use in the English language. After the Committee had been at work for a short time the German National Committee circulated a list of terms in regard to which it was considered by them to be of importance that international agreement should be reached at as early a date as possible. This list formed the basis of discussion of the definitions which were internationally accepted at Berlin last year.

The list proposed for international agreement was very much shorter and less complete than the list which the British Committee was working upon, and in view of this fact the British Committee decided to complete its work on the nomenclature of electrotechnical terms as used in this country, the object being, as far as possible, to record the present usage in this country in regard to terms used in electrotechnical work. The Committee has admitted certain obsolete and obsolescent terms which are met with in electrical literature, but it has not attempted to include neologisms which are not generally recognized. Slight differences of usage in the United States have been recorded.

In many instances the Committee has been guided and assisted by the definitions of the Danish, French, and German committees and by the list of terms and definitions adopted at the Berlin meeting in 1913 of the Nomenclature Committee of the International Electrotechnical Commission.

It is to be noted that the exact wording of some of the definitions does not coincide with that in the Berlin list. This is due to the fact that the intention is to put on record the usage in this country and not to set out what might be agreed upon internationally. It is hoped that the next revision will bring the two lists more nearly into line.

The present list must not be taken as final. The Committee is aware that there is considerable difference of opinion on the exact meaning and interpretation of some of the words, and it is hoped that by circulating the list, suggestions (which should be addressed to the Secretary of the Institution) may be received which will tend to eliminate any errors that may be present and to set up standard definitions which may be definitely accepted in this country.

Absolute. A system of magnitudes is said to be absolute when all the magnitudes of the system can be defined in terms of units adopted as fundamental.

An instrument for absolute measurements is one which can be standardized by means of measurements which involve only the fundamental units.

Accumulator. A reversible electrolytic cell of such a character that the electrical energy supplied to it is converted into chemical energy (a process called Charging). The chemical energy can be reconverted into electrical energy (a process called Discharging). Sometimes called a storage cell or a secondary cell. Several accumulators connected together in one circuit are sometimes called a storage battery or a secondary battery.

Active Current. Component of the current in phase with the voltage.

Admittance. The reciprocal of impedance. The quotient obtained by dividing the current in a conductor by the electromotive force which produces it.

Air-gap. *See* Gap.

Alternating Current. An electrical current which alternately reverses its direction around a circuit in a periodic manner. The time occupied by each pair of half-waves is called a Period or Cycle. Abbreviated A.C.

Alternation (A term not recommended). A half period. *See* Period, Frequency.

Alternator. A generator producing alternating electromotive forces and currents, either single phase or polyphase. An alternator may be described as a single-phase alternator, a two-phase alternator, a three-phase alternator, etc. The exciting current is generally supplied by a separate machine called an exciter. (The word Dynamo is usually reserved for a continuous-current generator.)

Ammeter or Amperemeter. An instrument with a scale graduated in amperes for measuring the value of an electric current.

Ampere. The practical unit of electric current. It is one-tenth of the centimetre-gramme-second (C.G.S.) unit.

Ampere-hour. A practical unit of quantity of electricity. One ampere for one hour, or its equivalent, such as four amperes for fifteen minutes, etc. One ampere-hour is 3,600 coulombs.

Ampere-turn. A practical unit of magnetomotive force. The number of turns or windings of a coil multiplied by the current in amperes which flows through it.

Anion. The ion which is carried to the anode.

Annunciator. An apparatus consisting of a series of devices for indicating which of several circuits is making a call.

Anode. (*a*) In an electrolytic cell. The conductor through the surface of which the current enters the liquid.

(*b*) In a primary cell. The metal (usually zinc) through which the current enters the electrolyte.

(*c*) The terminal by which the current enters a cell or other apparatus such as a vacuum tube, etc.

Antenna. A conductor or system of conductors for the emission or reception of Hertzian waves.

Antikathode. A target hit by the kathode rays in a vacuum tube.

Aperiodic. In an electrical instrument, the motion of the moving part is said to be aperiodic when it does not overshoot the mark on taking up a new position. Must not be confused with Dead Beat. *See also* Damped.

Apparent Power. In an alternating-current circuit the product of volts and amperes.

Arc. A luminous discharge of electricity through a gas in which the material of one or both the electrodes is volatilized and takes part in the conduction of the current whether continuous or alternating.

Armature (*a*) of a generator or motor. That part of the machine which consists of active windings, core, and supports, and which is acted upon inductively by the magnetic flux. In the case of a generator it supplies the main current to the terminals; in the case of a motor it receives the main current from the terminals.

Note to (*a*). In continuous-current machinery the armature usually rotates; in alternating-current machinery it is usually stationary. *See* Stator, Rotor.

(*b*) of a permanent magnet. An iron bar for completing the magnetic circuit; sometimes called a keeper. (Originally the pole-pieces attached to a lodestone.)

(*c*) of a simple electromagnetic mechanism. The movable iron part of the magnetic circuit which is not covered with wire; it is generally set in motion by an electromagnet.

Armouring of a cable. A protective metallic covering of wires or tapes, usually of iron or steel. (Verb: to armour.)

Arrester. An abbreviation. *See* Lightning Arrester.

Astatic. A system of magnets or coils is said to be astatic when the polarities of its parts are so adjusted that no directive effect is exerted on the system by a uniform magnetic field.

Asynchronous. A term applied to an alternating-current generator or motor the speed of which has no fixed relation to the frequency of the supply.

Auto-transformer. A transformer in which part of the winding is common to both the primary and the secondary circuits; sometimes called a Compensator.

Back Electromotive Force. *See* Counter Electromotive Force.

Balancer. A motor generator or accumulator used to equalize differences of potential between the different wires of a multiple-wire system.

Ballistic. An instrument in which the period of the moving part is long compared with the time of the duration of the transient force which the instrument is intended to measure.

Bank. A number of similar pieces of apparatus grouped and connected to act together is sometimes called a bank. Thus lamps are banked in parallel or in series, to form a resistance; and several transformers are banked to act as a single transformer.

Barretter. An instrument in which the current to be measured, generally alternating, flows through and heats a fine wire strip or filament, and causes a change in its resistance, from which change the current may be deduced.

Battery. Two or more cells or condensers electrically connected in one circuit.

Bifilar Suspension. The suspension of the moving part of an instrument by two threads, so arranged that the restoring force is mainly produced by gravity.

Bifurcating Box. A box containing the joints between a two-core and two single-core cables.

Blow (verb). When a fuse melts it is sometimes said to blow, a term suggested, probably, from the result of the melting of a fusible plug in a steam boiler.

Board of Trade. A British Government Department charged with the administration, *inter alia*, of the Electric Lighting and Power Acts, Railway and Tramway Acts, and of regulations made thereunder for the safety of the public, etc.

Board of Trade Unit. One kilowatt-hour. The expression Unit is officially used in Great Britain and not the expression Board of Trade Unit. *See* Kelvin.

Bolometer. An instrument in which the radiant energy is measured by the alteration of the resistance of a fine wire strip or filament.

Bond for tramway and railway rails. A connector, usually of copper, used for electrically connecting the rails to each other or to a return conductor in order to ensure good conductivity. (Verb: to bond.)

Boom. *See* Trolley. (U.S. equivalent, Pole.)

Booster. A dynamo, alternator, or transformer, interposed in a circuit for the purpose of increasing or decreasing the electromotive force acting in the circuit.

Bow. A bow-shaped appliance for effecting a sliding electrical connexion between an overhead conductor and an electrically-propelled vehicle.

Braiding. A plaited covering of fibrous material or wire. (Verb: to braid.)

Branch Circuit. A circuit which derives its supply of current from points on another circuit.

B.T.U., B.o.T.U. Abbreviation (not recommended) for Board of Trade Unit.

British Thermal Unit. The quantity of heat required to raise the temperature of one pound of water one degree from 60° F. to 61° F. Abbreviated B.Th.U. (U.S. abbreviation, B.t.u.) *See* Calorie.

Brush. A conductor for collecting or delivering current from commutators, slip-rings, or other contacts. Originally made of copper wires, afterwards of copper strips, gauze, or carbon blocks.

Brush Discharge. A discharge having a feathery form and consisting of an intermittent partial discharge which takes place from a conductor when the potential difference exceeds a certain limit, but is not high enough to cause the formation of a true spark. It is always accompanied by a hissing or crackling sound.

Brush-holder. The apparatus which holds the brushes.

Brush-rocker. The apparatus which enables the position of all the brushes carried by it to be altered simultaneously in either direction. (U.S. equivalent, Brush-rocker arm.)

B. & S. Abbreviation for Brown and Sharp's wire gauge.

Buckling of accumulator plates. The distortion caused by uneven expansion.

Bus-bar. Abbreviation for omnibus-bar. Conductors (generally on a switchboard and of comparatively large size) to which several mains or feeders or circuits are connected.

Busy-back. An electrical signal transmitted from one telephone exchange to another to indicate that the line wanted is in use. (U.S. equivalent, Busy signal.)

B.W.G. Abbreviation for Birmingham wire gauge.

C.G.S. Abbreviation for Centimetre-gramme-second.

Cable for electrical purposes. A stranded conductor with or without protective covering.

Calibrate. To mark the scale of an instrument, or to adjust the instrument to conform with the scale. (Sometimes used as the equivalent of to verify. Not recommended.)

Calorie. (*a*) The calorie or gramme calorie (also called the Small Calorie). The quantity of heat required to raise the temperature of one gramme of water one degree Centigrade. Equivalent to 4·2 joules.

(*b*) The kilo-calorie (also called the Great Calorie) is one thousand calories and is the quantity of heat required to raise the temperature of one kilogram of water one degree Centigrade.

Note.—The value of the calorie depends to some extent on the temperature at which the water is taken, and on the scale of the thermometer employed. The hydrogen thermometer is usually adopted as the standard, and the temperature selected is generally 15° C. or 20° C., or the mean 0° C.–100° C.

Candle-foot. A term not recommended. *See* Foot-candle.

Candle-power. A measure of the luminous intensity of a source of light in a given direction.

Capacity (*a*) of an accumulator. The quantity of electricity in ampere-hours which may be taken from a cell at a given rate of discharge.

(*b*) of a condenser. 1. Electrostatic. The capacity of a conductor at an infinite distance from other conductors is the quantity of electricity that must be imparted to it in order to raise its potential from zero to unity, *e.g.* the capacity of a sphere equals its radius.

2. The self-capacity of an insulated conductor is the charge on the conductor when its potential is unity, all the other conductors in the field being at zero potential. If the position of any of the other conductors is altered, the self-capacity will generally be altered also. Maxwell called this the capacity of the conductor and also the coefficient of self-induction of the conductor for electrostatic charges.

3. The mutual capacity between two insulated conductors when all neighbouring conductors are at zero potential is the induced charge on either of them when connected with the earth, the other being maintained at unit potential.

2 and 3 are also called the capacity coefficients.

4. The capacity between two insulated conductors when all neighbouring conductors are at zero potential is numerically equal to the charge on either of them when the potential between them is unity and they are given equal and opposite charges. This is the capacity in general use by electrical engineers; *e.g.* the capacity of a concentric main, the capacity between two overhead wires, between two cores of a multicore cable, etc. Many useful formulæ for this capacity are known.

(*c*) of a machine or of a generating station. This use of the word capacity is not recommended. The term Rating should be used.

Carcase of a dynamo, alternator, or motor. The assembled pole-cores, pole-pieces, and yoke or frame. (U.S. equivalent, Body.)

Carcel. The name of a standard oil-lamp, the official standard of ten candle-power used in France.

Cascade. (*a*) A series connexion of two or more condensers.

(*b*) A method of electrically connecting induction motors, whereby the secondary of one motor is connected electrically with the primary of the other. Also called Concatenation or Tandem.

Catenary. In railway work. A wire or cable from which electric wires or cables are hung. *See* Messenger.

Cathode. *See* Kathode.

Cell. (*a*) A source of electrical energy dependent on chemical action; complete in itself.

(*b*) A receptacle in which electrolysis takes place.

(*c*) A compartment of a high-pressure cellular switchboard.

(*d*) A combustion chamber of a dust or refuse destructor.

Characteristic. A curve or graph representing the relation between two magnitudes, which characterizes the behaviour of an apparatus; *e.g.* the exciting current of a dynamo and the electromotive force generated.

Charge (*a*) of a conductor. The total quantity of electricity on it.

(*b*) of an accumulator. *See* Accumulator.

(*c*) of a condenser. *See* Condenser.

Verb: to charge. The operation by which any apparatus receives a quantity of electricity, part or the whole of which it returns on discharge.

Choking Coil. A coil with so great a self-induction that its impedance depends chiefly on the self-induction rather than upon the resistance. (U.S. generally, Reactance coil.)

Circuit. The conductors connected with a source of electrical supply are collectively called a circuit. When they form a closed path through which a current circulates there is a closed circuit. When the path is not closed and no current circulates there is an open circuit.

Circuit Breaker. A switch which is opened automatically when the current or the pressure exceeds (or falls below) a certain limit, or which can be tripped by hand.

Closed Circuit. *See* Circuit.

Coercive Force. The magnetic force required to annul the residual magnetism of a substance.

Coherer. In wireless telegraphy. A device employed at the receiving end consisting essentially of an imperfect contact, or system of contacts, such that its resistance is altered on the reception of a signal.

Coil. One or more turns of a conductor wound side by side in one or more layers.

Collecting Rail. *See* Conductor rail.

Collector. A sliding piece which makes contact and collects the current from a fixed part of an electrical apparatus or vice versa.

Collector Ring. A ring used for making a sliding connexion between a fixed and a revolving part of an apparatus such as an alternator. *See* Slip-ring.

Commutator. (*a*) An apparatus for reversing the direction of a current in any circuit.

(*b*) In a dynamo or motor. A system of conducting bars insulated one from another on which the brushes press and collect or deliver the current.

Compensator. *See* Auto-transformer.

Compound Wound. A generator or motor is said to be compound wound when the magnetic field is excited

partly by series and partly by shunt coils, or by independently excited coils.

Concatenation. *See* Cascade.

Concentric Cable. A cable consisting of two or more separate conductors arranged concentrically with insulation between them. Three conductors so arranged form a triple concentric cable. The external conductor should be called External and not Outer in order to avoid confusion with the outer conductors of a three-wire system.

Condenser. An apparatus consisting of two conducting surfaces at a very small distance apart, separated by a dielectric.

Conductance. The conductance of a conductor is the quotient of the current by the potential difference between the terminals of the conductor.

Conductivity. The conductivity (specific conductance) of a substance is measured by the current which flows parallel to an edge through a unit cube of the substance, when unit difference of potential is maintained between the two faces perpendicular to that edge. The reciprocal is Resistivity.

Conductor. A body or substance which permits the passage of electricity.

Conductor rail. (Positive or Negative.) A rail employed on electric railways for conducting current to or from the train. The terms Live Rail, Third Rail, Fourth Rail, Collecting Rail, and Working Conductor are not recommended. (U.S., Third Rail almost always used.)

Conduit System (*a*) for electric light and power distribution. A system of bare conductors carried on insulators in a conduit or culvert, generally of concrete.

(*b*) for wiring. A system of metal or other pipes into which wires are drawn.

(*c*) for traction. A system of bare conductors carried in a conduit, having an open slot through which a plough makes contact between the conductor rails and the electrical equipment of the car.

(*d*) for telegraphs and telephones. A group or collection of ways or passages called Ducts into which cables are drawn.

Consumers' Load Factor. The number obtained by dividing the actual consumption during a given period by what that consumption would have been had the maximum load reached during that period continued in use throughout the whole of that period.

Contactor. An electromagnetic, electro-pneumatic, or automatic switch used for controlling heavy current circuits to motors, and which is itself controlled by a master or pilot controller.

Contact Resistance. A quality acting like a resistance which appears at the surface of contact between two conductors (*e.g.* as between brushes and commutator or slip-rings).

Contact Ring. A conducting ring for effecting a connexion between a revolving conductor and a fixed conductor as in a crane, a searchlight, a ship's turret.

Continuous Current. An electric current in one direction and sensibly steady or free from pulsation. Abbreviated C.C. The term Direct Current is not recommended. (The term Direct Current is much used in U.S.)

Continuous Running. Running for such a time, under specified conditions, that the final state is sensibly attained.

Controller. A compound or multiple switch containing the means for introducing resistances, or for connecting motors in series or in parallel. It has several steps or positions called Notches, and is intended for use on any notch for an appreciable period of time. It is to be distinguished in this respect from a starting-switch or starter. It is used for varying the speed or power of, as well as for starting, traction or other motors. A master controller, sometimes called a pilot or multiple-unit controller, does not act directly on the current supplied to the motors, but works contactors.

Converter. A machine having an armature with a commutator and slip-rings revolving in a magnetic field for converting single or polyphase alternating current into continuous current or vice versa; sometimes called a Rotary Converter. To be distinguished from a transformer, rectifier, or motor generator. (U.S. equivalent, Synchronous converter.)

Copper-loss. The total losses in the copper windings.

Core (*a*) of a magnetic circuit. That part which is within the winding. The part outside the winding, if any, is called the Yoke.

(*b*) of a transformer. The whole of the iron forming the magnetic circuit.

(*c*) of a cable. The conductor with its insulation or dielectric, not including the mechanically protecting covering. Two, three, or more cores may be laid together to form a twin, three-core, or multi-core cable.

(*d*) of an arc lamp carbon. The longitudinal filling.

Corona. The luminous discharge which appears round a conductor when its potential exceeds a certain value, depending on barometric pressure, the diameter of the conductor, etc.

Coulomb. The practical unit of electrical quantity. One coulomb is equivalent to one ampere flowing for one second; 3,600 coulombs equal one ampere-hour. The term Ampere-hour is almost universally adopted; the coulomb is seldom used.

Counter Electromotive Force or back electromotive force. An electromotive force which opposes the flow of the current in the circuit.

Cut-out. An automatic device for protecting apparatus from damage by overload. The term comprises all the separate parts which, together with their mountings and base, form the complete device, and it includes fuses and circuit breakers.

Cycle. A term not recommended as a synonym for period. *See* Period, Alternating Current. (Used in U.S.)

Damped. The motion of a piece of mechanism is said to be damped when any oscillations which may be started rapidly die away. If no oscillations can be produced it is said to be Aperiodic. *See* Dead Beat.

Damper. A special short-circuited winding on the poles of a generator or converter to diminish oscillations.

Dash-pot. An appliance for preventing sudden or oscillatory motion of any portion of an apparatus by the friction of air or of a liquid.

Dead Beat. An instrument or other mechanism is said

to be dead beat when the oscillatory movement rapidly dies away. To be distinguished from Aperiodic.

Decohere. To restore a coherer to its original state of resistance.

Delta. A mode of connexion in three-phase alternating-current working, in which three windings or pieces of apparatus are so connected that they may be diagrammatically represented by a triangle. A particular form of mesh.

Derived Unit. *See* Practical Unit.

Diamagnetic. A substance of which the magnetic permeability is less than that of a vacuum (unity).

Dielectric. Any material which offers high resistance to the passage of an electric current.

Dielectric Rigidity or **Dielectric Strength.** The property of a dielectric to resist the passage of sparks. (In practice, measured in volts per centimetre under specified conditions.)

Direct Current. A term not recommended. *See* Continuous Current.

Discharge (*a*) of a condenser. An operation which tends to bring the two conducting surfaces of a condenser to the same potential.

(*b*) of an accumulator. An operation which tends to bring the two plates of an accumulator to the same potential and which permits the chemical energy to be reconverted into electrical energy and utilized in an outside circuit.

Discriminating Cut-out. A cut-out, usually on a switchboard, for interrupting the circuit when the normal direction of the flow of energy is reversed. (U.S. equivalent, Reverse circuit breaker.)

Disruptive Discharge. The breaking down of a dielectric under electric stress, accompanied by sparking.

Disruptive Voltage. Difference of potential producing a spark discharge.

Distributing Board. A board carrying small bus-bars, used for connecting a number of circuits to a pair of mains. Sometimes called a Distribution Board.

Distributing Mains or **Distributor.** The conductors which intervene between the feeders and the service lines and which are collectively called the Distributing Network or Low-pressure Network, or the Network.

Diversity Factor. The number obtained by dividing the sum of the maximum load of the individual consumers supplied from any works during a given period by the maximum load delivered from the works during the same period.

Draw-in Box. A box used in connexion with a draw-in system of mains. When complete it contains no links, fuses, or switches, but in some cases permanent joints.

Draw-in System. A system of laying mains in which the cables or wires are drawn into pipes or ducts after the latter have been laid or fixed in position, in such a manner that the cables or wires can be withdrawn at any time without disturbing the pipes or ducts. Draw-in boxes, manholes, or junction boxes are usually provided through which the cables or wires may be drawn in or withdrawn.

Drop (in pressure). Synonym for Fall of Potential.

Drop Signal. *See* Annunciator.

Ducts. Pipes or blocks perforated with holes through which cables are drawn. Usually non-metallic and set in concrete. The holes themselves are sometimes called ducts.

Dynamo. A continuous-current generator.

Dynamometer. (*a*) An instrument for measuring forces.

(*b*) An apparatus for measuring the torque exerted by a prime mover or motor.

(*c*) An instrument for measuring electric currents depending on the measurement of the electromagnetic forces between two or more coils. (Abbreviation for Electro-dynamometer.)

Ear. In overhead tramway work. A grooved metal fitting riveted over, soldered, or otherwise attached, to a trolley wire for the purpose of—

(*a*) supporting the wire.

(*b*) altering the horizontal direction of a trolley wire, then termed a Pull-off Ear.

(*c*) anchoring a trolley wire.

Earth. (*a*) An electrical connexion with the earth, intentional or unintentional, is called an Earth. (U.S. equivalent, Ground.)

(*b*) (Verb : to earth.) To connect any conductor with the general mass of the earth in such a manner as will ensure at all times an immediate and safe discharge of electrical energy. (Board of Trade definition of Efficiently connected with Earth.)

(*c*) Earth circuit. A circuit of which the earth forms a part.

Earthed Circuit. A circuit one pole of which is earthed at one or more points. (U.S. equivalent, Grounded.)

Earth Rail. *See* Conductor Rail.

Eddy Current. A current induced in a conducting body either by a varying magnetic field or by the body moving relatively to a fixed magnetic field.

Effective Volts. A term not recommended. *See* Virtual Volts.

Efficiency. 1. In the case of generators, motors, converters, or transformers. The ratio of the total output to the total input; *e.g.* in the case of a separately excited synchronous generator the excitation power should be added to the power received at the shaft.

2. In the case of accumulators—

(*a*) The ratio of the amount of energy available during the discharge to the amount of energy required during the charge (Watt-hours).

(*b*) The ratio of the quantity of electricity available during the discharge to the quantity of electricity required during the charge (Ampere-hours).

E.H.P. Abbreviation for Electrical Horse-power.

Electrocution. A form of capital punishment for criminals by electric shock.

Electrode. A conductor by which an electric current passes into or out of an electrolyte or other substance.

Electro-dynamometer. *See* Dynamometer.

Electrolysis. The decomposition which takes place when an electric current passes through a chemical compound.

Electrolyte. Any substance which undergoes chemical decomposition by the direct action of an electric current passing through it.

Electrometer. An instrument which utilizes electrostatic forces for the measurement or comparison of differences of potential.

Electromotive Force. That which causes or tends to

cause an electric current. Abbreviated, E.M.F. *See* Potential, Pressure, Tension, Voltage.

Excitation. (*a*) Production of the magnetic flux in an electro-magnet by means of an exciting current.

(*b*) Number of ampere-turns producing the flux.

Note: The excitation may be produced by several windings traversed by different currents.

Exciter. A dynamo used for producing the excitation of the field magnets of another machine. *See* also Alternator.

Extra Current. An obsolete term. The current during the variable period on closing or opening an inductive circuit.

Extra High Pressure. *See* Pressure.

Factor of Safety. In mechanics, the ratio of the ultimate breaking stress to the maximum normal working stress.

Farad. In the practical system of units the farad is the unit of electrical capacity. It is inconveniently large, and therefore capacities are usually expressed in microfarads.

Fault. Any local defect in the insulation or continuity of a conductor which may interfere with its use.

Feeder. A conductor for conveying electrical energy from the place where it is generated or transformed to feeding-points or sub-stations. Feeders are not used for supplying consumers directly, owing to the varying pressure along their length.

Feeder Box or Pillar. A box or pillar which may contain switches, links, or fuses for connecting feeders with distributing mains. (U.S. equivalent, Junction box.)

Feeder, Negative. *See* Return Feeder.

Feeding Point. The junction of a feeder with a network.

Ferro-magnetic. A substance of which the permeability is greater than that of a vacuum (unity). *See* Paramagnetic.

Field, Electromagnetic. *See* Field, Magnetic.

Field, Electrostatic. Any region in which there are electric lines of force, as in the space between a positively charged and negatively charged surface.

Field Magnet. Any permanent magnet or electro-magnet employed for the purpose of providing a magnetic field. (It is incorrect to speak of the field magnets of a dynamo or motor as its fields: they should be called its Magnets, if the term field magnets is too long.)

Field, Magnetic. Any region in which there are magnetic lines of force, as in the space between or surrounding the poles of a magnet or within a magnetizing coil. The strength of the field is usually expressed in C.G.S. measure as the number of lines per square centimetre. One line per square centimetre is called a Gauss. *See* Line and Maxwell.

Figure of Merit, (1) of a galvanometer. (*a*) The deflexion in millimetres per micro-ampere at a scale distance of one metre when reduced to a period of 10 seconds and a resistance of one ohm.

(*b*) The current in amperes required to produce a deflexion of one millimetre at a scale distance of one metre. Sometimes expressed as the number of megohms through which one volt will give that deflexion.

(2) of a telegraph instrument. The minimum current necessary to work the instrument with absolute certainty.

Flame Arc. An arc in which the major portion of the light is given by the flame instead of by the electrodes. (U.S. equivalent, Flaming arc.)

Flashing. (*a*) Any process of manufacture involving the temporary electrical overheating of a glow lamp filament.

(*b*) The coating of a glow lamp filament with a layer of carbon by heating it electrically in a hydrocarbon vapour.

Flashing Over. The temporary formation of an arc from brush to brush on a commutator.

Flash Test. The momentary application of a high electrical pressure between two conductors insulated from each other.

Flux. (*a*) Magnetic. The number of lines of magnetic induction which pass round a magnetic circuit. *See* Induction.

(*b*) Photometric. The whole luminous radiation of a beam of light, or the candle-power multiplied by the solid angle of the beam.

(*c*) Chemical. Material used for reducing or dissolving the oxides of molten metals in casting, soldering, brazing, etc.

Foot-candle. The illumination received from a source of one candle-power falling perpendicularly on a surface at a distance of one foot from the source.

Form Factor. The ratio of the virtual value to the mean value of a periodic function.

Fourth Rail. *See* Conductor Rail.

Frequency. Reciprocal of the time for a complete period of a periodic quantity. In practice, the Number of Periods per second.

Friction Loss. Loss due to mechanical friction exclusive of windage.

Frog. In tramway overhead work. A fitting uniting two diverging trolley wires with a single wire, (*a*) provided with a spring tongue, or (*b*) of the fixed type.

Fuse. The actual wire or strip of metal in a cut-out which is fused by an excessive current.

Galvanometer. An instrument for measuring small electric currents.

Gap, Magnetic Air-. Any gap in a magnetic circuit filled with air or other diamagnetic substance.

Gap, Spark-. Any break in the continuity of a metallic conductor so arranged as to permit of an electric discharge across the break.

Gauge. (*a*) A general term applied to various kinds of measuring instruments.

(*b*) The thickness of a plate, or the diameter of a wire, on the inch, millimetre, or on any arbitrary scale.

(*c*) The distance between the rails of a railway or of a tramway. In the case of a railway it is the distance between the inner sides of the heads of the rails. In the case of a tramway it is the distance between the inside edges of the tread of the rails, *i.e.* over and including the grooves.

Gauss. A name given to the absolute electromagnetic unit of magnetic force in the C.G.S. system. *See* Field, Magnetic-, and Line.

Generating Set. A combination of a generator and a prime mover.

Generator. A machine for converting mechanical energy into electrical energy. A term including Dynamo and Alternator.

Glow Discharge. A silent discharge of electricity through a gas which causes the gas to have a uniformly luminous appearance or glow, and which does not volatilize the electrodes.

Glow Lamp. A lamp in which the filament or wire is caused by the current to glow or incandesce. A term recommended instead of Incandescent Lamp in order to avoid confusion with the incandescent gas mantle.

Gramme Calorie. *See* Calorie.

Great Calorie. *See* Calorie.

Grid. (*a* In an accumulator. The framework supporting the active material.

(*b*) A form of cast or stamped resistance.

Ground. A term used in America having the same meaning as Earth.

Henry. The practical unit of the coefficient of self-induction or of mutual induction in the electromagnetic system.

High Pressure. *See* Pressure.

High Tension. Term sometimes used for High Pressure.

Homopolar Dynamo or Motor. A dynamo or motor in which the inductive action takes place in a magnetic field or a series of magnetic fields, without change of sign.

Homopolar Induction. A term sometimes applied to the induction which occurs when a conductor is moved through a magnetic field, so as to cut the lines of force in the same direction continuously. Sometimes called Unipolar.

Horse-power. The industrial unit of power. The British horse-power is equivalent to 33,000 foot-pounds per minute or (approximately) 746 watts.

Hot Wire Instrument. An instrument the indication of which depends on the expansion of a wire or wires through which an electric current flows.

Hysteresis. The lagging of the strain behind the stress, which when the material is taken round a complete cycle and brought back to the initial state, involves a dissipation of energy.

Hysteresis Loss. Power dissipated in iron by reason of magnetic hysteresis.

Hysteresis, Magnetic. The tendency by which changes of magnetism lag behind the changes of magnetic force which cause them.

Impedance. The ratio of the electromotive force to the current which is produced by it in a conductor. The term is used with varying or alternating currents.

Incandescent Lamp. *See* Glow Lamp.

I.H.P. Abbreviation for Indicated Horse-power.

Inductance. (*a*) Synonym for Coefficient of Self-induction.

(*b*) The reactance due to self-induction. *See* Reactance. (Not used in U.S.)

Induction. When an electric or a magnetic force acts, through the ether, upon a body so as to alter its electric or magnetic state, that alteration of state is said to be induced in it, as distinguished from alterations of state communicated to it by conduction or contact. The operation of inducing alteration of state is called Induction. The three chief induced actions are (*a*) Induced Electrostatic Charge, (*b*) Induced Magnetism, (*c*) Induced Electromotive Force.

Induction, Electrostatic. When a body is brought into an electric field, thereby causing an electric charge or charges to appear on the body, these charges are called Induced Charges, and the operation is called Electrostatic Induction.

Induction, Magnetic. (*a*) When a mass of iron, etc., is brought into a magnetic field, thereby causing magnetic poles to appear on the mass, these poles are called Induced Poles, and the magnetism so acquired is called Induced Magnetism ; and the operation is termed Magnetic Induction.

(*b*) When a uniform magnetizing force **H** acts on a medium it produces a flux of induction the density of which is **B**. Flux of induction is also called Magnetic Flux. The ratio **B/H** gives the permeability of the medium for the value **H**. The unit line of magnetic induction (the Maxwell) is called a Magnetic Line.

Induction, Magneto-electric. When a body is subjected to the action of a varying magnetic field, thereby causing electromotive force to be generated in the body, these electromotive forces are called Induced Electromotive Forces, any currents that result in the body are called Induced Currents, and the operation of thus inducing electromotive forces and currents is called Magneto-electric Induction.

Induction Motor. An alternating-current motor in which the secondary part receives its current by magneto-electric induction and not by conduction.

Induction, Mutual. The (magneto-electric) induction exercised between two circuits, whereby the variations of the current in one circuit generate electromotive forces in the other circuit is called Mutual Induction. This mutual relation may be quantitatively expressed by means of a Coefficient of Mutual Induction.

Induction, Mutual, the Coefficient of, is the sum of the effective linkages of the turns of one circuit (the secondary) with the flux due to unit current in the other circuit (the primary). Symbol, **M**.

Induction, Self-. The (magneto-electric) induction exercised upon the turns of a circuit by the current in itself is called Self-induction. It may be quantitatively expressed by means of a Coefficient of Self-induction.

Induction, Self-, the Coefficient of, is the sum of the linkages of flux and current when the current in the coil is unity. The (total) Self-induction of any coil is the product of its Coefficient of Self-induction and the current it is carrying. Symbol, **L**.

Induction, Unipolar. *See* Homopolar.

Inductive Capacity, Specific. *See* Capacity.

Inductive Circuit. A circuit in which the reactive effect of self-induction at the working frequency or at make or break is appreciable compared with its resistance.

Inductive Load. *See also* **Lagging Load.** An output at a power factor which by reason of self-induction is less than unity.

Inductive Resistance. A resistance having appreciable self-induction.

Inductor Generator. A generator with stationary field and stationary armature coils and in which masses of iron or inductors by moving past the coils alter the magnetic flux through them.

Inductors. In inductor generators. The masses of iron employed to effect variations of the magnetic flux passing through the armature coils.

Input. The total power received at the shaft or terminals of a machine or apparatus.

(*a*) Power supplied to a generator or transformer.

(*b*) Power supplied to the terminals of a motor.

Insulance. A term proposed in place of the expression Insulation Resistance.

Insulate (verb). To surround or support a conductor by non-conducting bodies or materials so as to restrict the flow of electricity to the desired path.

Insulation. (*a*) Process of insulating.

(*b*) Material employed to insulate.

(*c*) Quality resulting from the process.

Insulation Resistance. The resistance of the insulation between two conductors or systems of conductors, or between a system of conductors and earth. (Usually expressed in megohms.)

Insulator. (*a*) Any material which does not appreciably conduct electricity.

(*b*) An appliance used to insulate and usually to support a conductor.

Integrating Meter. A meter which sums up or integrates the quantity to be measured, with reference to time. *See* Watt-hour Meter.

Intensity. There is an increasing disposition to restrict the use of the word Intensity in English physical science to a ratio, the denominator being an area. The older meaning was synonymous with Strength.

Intensity of Current. An obsolete expression. It has been replaced by Strength of Current.

Intensity of Field, Magnetic. *See* Field, Magnetic.

Intensity of Light. The illuminating power or candle-power of a source of light.

Intensity of Magnetization. The magnetic moment per cubic centimetre.

Intermediate, The. The intermediate or neutral or middle wire or wires of a three-wire or multiple-wire system. (U.S. equivalent, Neutral.)

Interpole. An intermediary pole placed between the principal poles of a machine to assist commutation.

Interrupter. Sometimes called Break. A mechanism or device used to break the primary circuit of an induction coil.

Ion. An ion is a charged atom or molecule, or a group of atoms or molecules carrying a charge.

Isolating Link. A link used for disconnecting a circuit.

Joule. A unit of heat equivalent to 0·24 calorie, or one watt-second.

Joule Effect. The heating in a conductor by the passage of an electric current through it, and due to the resistance of the conductor.

Kathion. The ion which is carried to the kathode.

Kathode. (*a*) In an electrolytic cell. The conductor through the surface of which the current leaves the electrolyte.

(*b*) In a primary cell. The conductor (generally carbon) through which the current leaves the electrolyte.

(*c*) The electrode by which the current leaves a cell or other apparatus such as a vacuum tube.

Keeper, of a Magnet. An iron bar for completing the magnetic circuit (usually of a permanent magnet). *See* Armature.

Kelvin. A term officially proposed and authorized by the Board of Trade, May, 1892, but which has not come into common use, for a Kilowatt-hour.

Key. An appliance consisting essentially of a lever carrying a contact or contacts, generally used in signalling and in testing.

Kicking Coil. Name given in U.S. to a Choking Coil used in conjunction with lightning arresters.

Kilowatt. A unit of power. One thousand watts. Equivalent to 1·34 British horse-power (approximately).

K.V.A. Abbreviation for Kilo-volt-ampere, or one thousand volt-amperes.

K.W. Abbreviation for Kilowatt.

Lag. The interval of time or angle by which one event follows another. *See* Phase Difference.

Lagging Current. An alternating current, the phase of which is retarded in time relatively to the impressed electromotive force.

Lagging Load. Any load on a machine or apparatus in which the phase of the current lags behind that of the voltage at the terminals.

Lamination. The division of a mass of material into thin sheets either to prevent eddy currents or to give flexibility. The thin sheets or stampings of iron forming part of a magnetic circuit are often called the laminations.

Lay, in a cable. The pitch or length parallel to the axis of one complete turn in the spiral arrangement of a stranded cable may be expressed (*a*) as a multiple of the diameter of the layer considered; or (*b*) as the increase in length of a strand above the length of the cable, expressed as a percentage of the length.

Lead. (*a*) Of a conductor or pipe. Its direction or run.

(*b*) Sometimes used as a synonym for a Conductor.

(*c*) Of an alternating quantity. The interval of time or angle by which one event precedes another. *See* Phase Difference.

Leading Current. An alternating current the phase of which is in advance in time relatively to the impressed electromotive force.

Leakage. (*a*) The passage of electricity from one conductor to another or to earth, caused by want of perfect insulation.

(*b*) Magnetic. That part of the magnetic flux which does not follow the path provided for it.

Leakance. The reciprocal of Insulance.

Leyden Jar. A condenser in its original form of a jar, generally of glass, having a conducting surface inside and out.

Lightning Arrester. An appliance for protecting electrical apparatus by providing an alternative discharge path.

Limiter. A device for giving warning when a predetermined current is exceeded.

Line, Telegraphic. That part of a telegraph, telephone, or railway signalling circuit, whether aerial, underground, or submarine, which does not include the controlling or operating apparatus and the source of power. Used also, collectively, for a group of wires including poles, pipes, junction boxes, etc.

Lines of Force. (*a*) Magnetic. A line such that the tangent to it at any point represents the direction of the magnetic force at that point.

By convention the magnitude of the magnetic force

at any point is represented by supposing as many magnetic lines of force to be drawn through one square centimetre (situated around the point) as there would be dynes exerted on unit pole if placed at that point. Unit intensity, *i.e.* one dyne per unit pole, or one line per square centimetre is called one Gauss. *See* Magnetic Flux.

(*b*) Electrostatic. A line such that the tangent to it at any point represents the direction of the electric force at that point.

By convention the magnitude of the electric force at any point is represented by supposing as many electrostatic lines of force to be drawn through one square centimetre (situated around the point) as there would be dynes exerted on one unit of positive electricity placed at that point.

Link. A readily removable conductor forming part of a circuit, generally in the form of a flat bar. *See* Isolating Link.

Linked Switches. Switches linked together mechanically so as to operate simultaneously.

Load. (*a*) Synonym for Output.
(*b*) Synonym for Weight.

Loaded. Telegraph line or cable. A line or cable the self-induction of which has been intentionally increased.

Load Factor. The number obtained by dividing the actual output of a generator or of a whole generating station during a given period by the output if the maximum had been maintained during that period.

Looping-in. Bringing a wire as a loop to and from a terminal to avoid making a T joint.

Loop Test. A method of testing employed to locate a fault in a telegraph or other conductor when it can be arranged to form part of a closed circuit.

Loss, Total. The difference between input and output.

Low Tension. Term sometimes used for Low Voltage.

Magnet Coil, Magnetizing Coil. The winding used to magnetize an electromagnet, such as the field magnet of a dynamo. Sometimes called Field Coil.

Magnet, Permanent. A body which having been magnetized retains a substantial portion of its magnetization.

Magnet Winding. A set of magnet coils.

Magnetic Blow-out. An apparatus so arranged as to produce a magnetic field which breaks the arc formed on opening the circuit.

Magnetic Field. *See* Field, Magnetic.

Magnetic Flux. The number of magnetic lines which pass through any area is called the Flux through that area. In the case of a magnetic circuit, the number obtained by dividing magnetomotive force by reluctance. Unit, One Line or Maxwell.

Magnetic Flux Density. The number of magnetic lines per square centimetre. The number obtained by multiplying magnetic force by permeability. *See* Induction, Magnetic.

Magnetic Force. The force at any point in a magnetic field experienced by a unit pole placed at that point, divided by the permeability of the medium; sometimes called Field Intensity or Strength of Field.

Magnetic Line. The unit (*a*) of magnetic flux **B**, or (*b*) magnetic induction **B**. The rate at which the number of magnetic lines linked with a circuit alters equals the electromotive force induced in the circuit.

Magnetic Permeability. Magnetic conductivity or specific permeance compared with unity (vacuum). The number obtained by dividing magnetic flux-density in a substance by magnetic force.

Magnetic Permeance. Sometimes called Magnetic Conductance. The number obtained by dividing magnetic flux by magnetomotive force.

Magnetic Reluctance. The reciprocal of magnetic permeance (sometimes called Magnetic Resistance, a term not recommended).

Magnetic Reluctivity. Specific magnetic reluctance. The reciprocal of the permeability of a substance.

Magnetic Remanence. Residual flux-density after the magnetizing force has been removed.

Magnetic Resistance. A term not recommended. *See* Magnetic Reluctance.

Magnetic Susceptibility, or **Magnetizability.** The number obtained by dividing the intensity of magnetization by the magnetic force producing it.

Magnetizability. *See* Magnetic Susceptibility.

Magnetization. The process or result of communicating magnetism to a body.

Magnetize. To give a body the properties of a magnet.

Magneto. Contraction for magneto-electric generator. A generator whose field magnets are permanent magnets.

Magnetometer. An instrument for measuring the magnitude and direction of magnetic force.

Magnetomotive Force. That which causes or tends to cause a magnetic flux. The unit is $4\pi/10$ ampere-turns. The industrial unit is the ampere-turn.

Main. Any conductor forming part of a distributing network. The principal conductors are collectively called the Mains. *See* Feeder and Trunk Main.

Master Controller or **Pilot Controller.** A controller used in the multiple-unit system of electrification and for the distant control of electric motors. It does not act directly on the current supplied to the motors, but works electromagnetic or other switches called Contactors. These contactors control the motors.

Maximum Demand System. A system for assessing the payment to be made for a supply of electrical energy, composed of two parts, (1) a sum depending on the maximum power supplied during a certain period; and (2) a sum proportional to the energy supplied during that period.

Maxwell. The name given to the magnetic line of force or (*a*) unit of magnetic flux, (*b*) unit of magnetic induction.

Meg-, Mega-. A prefix signifying one million times, *e.g* megohm, one million ohms; megavolt, one million volts.

Mesh. A mode of connexion in polyphase alternating-current working, in which windings or apparatus are so connected that they may be diagrammatically represented by a closed figure.

Messenger. A name used in America for a wire or cable from which electric wires or cables are hung. Called in railway work a Catenary, in telephone and telegraph work a Suspending Wire.

Mho. A term proposed for the unit of conductance. The reciprocal of the ohm. The conductance of a circuit the resistance of which is one ohm.

Micro-. A prefix signifying one-millionth part; *e.g.* micro-ampere, one-millionth of an ampere; microfarad, one-millionth of a farad.

Micron. One-millionth of a metre; one-thousandth of a millimetre. Symbol, μ.

Microphone. A device employed at the transmitting end of a telephone circuit, consisting of a contact or system of contacts such that the resistance is altered by the impact of the sound waves.

Middle Wire. The conductor of a three-wire system of supply the potential of which is intermediate between those of the other two. Sometimes called the Intermediate or Neutral.

Mil. One-thousandth of an inch.

Mil, circular. A unit used in America. The area of a circle of which the diameter is one-thousandth of an inch.

Milli-. A prefix signifying one-thousandth part; *e.g.* milliampere, one-thousandth of an ampere.

Milker. A dynamo used for charging individual cells forming a portion of a battery of accumulators. Sometimes called milking booster.

Mirror Galvanometer. A galvanometer having a mirror attached to the moving part. A beam of light reflected from the mirror is used as a pointer, or the image of a scale is observed in the mirror by means of a telescope.

Moment (*a*) of a force. The tendency of a force to produce rotation about a point. The product of the magnitude of the force and the length of the perpendicular let fall on its line of action from the point.

(*b*) of a couple. The product of the magnitude of one of the two equal forces and the arm or perpendicular distance between them.

(*c*) of a magnet. The product of the strength of either of the poles of a magnet and the distance between them.

Morse Alphabet. A signalling code in which two different signals arranged in groups of one or more, are used to represent a letter, figure, or symbol.

Motor. A machine for converting electrical energy into mechanical energy.

Motor Generator. A machine consisting of a dynamo or alternator driven by an electric motor, either in the form of two distinct parts coupled together, or having the armature windings on a common core and revolving in a common field. In U.S., where the two component armatures are placed in one and the same field, the machine is called a Dynamotor.

Motor Transformer. A term not recommended. *See* Transformer.

Mouse Mill. A special continuous-current motor used for running paper strip through a siphon recorder.

Moving-Coil Instrument. A measuring instrument, the indication of which depends on the torque exerted by a magnetic field on a coil through which an electric current passes.

Multicellular voltmeter or **electrometer.** An instrument in which several pairs of quadrants act on several needles mounted on one axis.

Multiphase. Synonym for Polyphase.

Multiple Arc. Synonym for connexion in Parallel. A term not recommended.

Multiple Board. A form of telephone switchboard.

Multiple-Unit System. A system of electric traction in which two or more cars are units in themselves and have their own motors, controlled by electromagnetic or other switches called Contactors. When the cars are coupled together as a train, the contactors can all be worked from a single Master Controller.

Multiplex Telegraphy. A telegraphic system in which several messages generally more than two in both directions can be transmitted on one circuit at the same time.

Multipolar Generator or Motor. A dynamo, alternator, or motor, having more than one pair of magnetic poles.

Mutual Induction. *See* Induction, Mutual.

Needle. A name originally applied to the moving magnet of a mariner's compass, later to the similar magnet of a galvanometer, and to the paddle-shaped moving conductor of a quadrant electrometer.

Needle Astatic. *See* Astatic.

Negative. Of the two poles of any source of electricity that one is called Negative which corresponds as far as the direction of the current in the external circuit is concerned to the zinc plate of a Daniell cell.

Network. A system of conductors consisting of mains, feeders, and distributors interconnected for the distribution of electrical energy in a supply system.

Neutral Points on a dynamo commutator. Those points between which there is a maximum electromotive force when the dynamo is running on open circuit.

Nominal Horse-power. An obsolete mode of describing the output of a steam engine in terms of certain of its dimensions.

Non-inductive. (*a*) **Circuit.** A circuit so arranged that its self-induction is practically negligible.

(*b*) **Winding.** Two identical insulated conductors laid side by side or twisted together and so connected that a current traversing them in opposite directions generates no sensible magnetic field.

(*c*) **Load.** Any load on a machine or apparatus in which the current is in phase with the voltage at the terminals.

Ohm. (*a*) **True.** The unit of resistance in the Practical System of units. The value in the C.G.S. system is equal to 10^9 electromagnetic units.

(*b*) **International.** The resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14·4521 grammes in mass, of a constant cross-sectional area and of a length of 106·300 centimetres. (International Conference, 1908, and British Order in Council, 10th January, 1910.)

Ohmmeter. An instrument for measuring electrical resistance by the deflexion of a pointer over a scale.

Oil Transformer. A transformer immersed in oil.

Omnibus-bar. *See* Bus-bar.

Oscillation Circuit. A circuit in which electrical oscillations can freely take place.

Oscillation, Electric. When a system or circuit possessing capacity and self-induction is disturbed from its condition of electrical equilibrium, electric oscillations occur flowing alternately in opposite directions with decreasing amplitude during the return to equilibrium.

Oscillator. A conductor having effectively both self-induction and capacity in which electric oscillations can be set up.

Oscillograph. An apparatus for observing or recording quickly varying currents or potential differences.

Outer. The two conductors of a three-wire system between which there is a maximum voltage are called the outers. A term not recommended as a synonym for the external conductor of a concentric cable.

Output. The power given out—

(*a*) At the terminals of a generator, converter, or transformer. A synonym for Load.

(*b*) At the shaft of a motor.

See Rated output.

Over-compounded. A compound-wound generator or motor is said to be over-compounded (*a*) when the potential difference between its terminals increases with the load, (*b*) when the speed increases with the load.

Over-load. A load greater than the rated load.

Over-load Circuit Breaker. An automatic switch which opens when a predetermined load is exceeded.

Parallel. (*a*) Two or more systems of conductors are said to be in parallel in a circuit when the current flowing in the circuit is divided between the two systems.

(*b*) Two or more systems of conductors, generators, or motors are said to be connected in parallel when the terminals of the same sign are electrically connected together.

Paramagnetic. A substance of which the magnetic permeability is greater than unity (vacuum).

Paste of an accumulator. The active material of the plates or grids of an accumulator. So called as it is sometimes applied as a moist composition or paste.

Peltier Effect. The liberation or absorption of heat which takes place in a heterogeneous circuit at the joint where an electric current passes from one material to another.

Period, Periodic Time. Any varying quantity which repeats its values regularly at equal time-intervals is said to be periodic, and the time interval of one repetition is called the periodic time or period.

Permanent Magnet. A body which having been magnetized retains a substantial portion of its magnetism.

Permeability. *See* Magnetic Permeability.

Permeance. *See* Magnetic Permeance.

Phase. (*a*) In an operation which recurs harmonically, the stage or state to which the operation has proceeded.

(*b*) In an operation which recurs harmonically, the fraction of the whole period which has elapsed, measured from some fixed origin.

(*c*) **Phase difference.** The difference of phase (usually reckoned in time or in angle) between two periodic quantities which vary harmonically and have the same frequency. *See* Lag.

(*d*) Each of the circuits of a polyphase apparatus is sometimes called a phase.

(*e*) **Single-phase.** A supply is said to be single-phase when it consists of a single alternating current.

(*f*) **Two-phase.** A supply is said to be two-phase when it consists of two alternating currents which are displaced with regard to one another by one-quarter of a period. In U.S. Quarter-phase is often used in place of Two-phase.

(*g*) **Three-phase.** A supply is said to be three-phase when it consists of three alternating currents displaced with regard to one another by one-third of a period.

(*h*) **Polyphase.** A supply is said to be polyphase when it consists of alternating currents displaced in phase with regard to one another by equal portions of a period.

Phase-angle. The angle between two vectors representing two simple harmonic periodic quantities having the same frequency but differing in phase from one another, *e.g.* the vectors representing alternating voltage and the current produced by it.

Extended meaning. The angle between any two vectors which represent quantities having the same fundamental frequency.

Phasemeter. Apparatus for measuring the difference of phase between two periodic electric quantities of the same frequency.

Photoelectric Effects. Any changes in the electrical properties of a body produced by the action of light, *e.g.* generation of electromotive force, change of resistance, or loss of charge.

Piezoelectric Effect. The production of electrification by mechanical pressure.

Pile. (*a*) **Thermo-electric.** A source of electrical energy due to the direct transformation of heat into electrical energy, generally consisting of a series of thermo-junctions.

(*b*) **Voltaic.** An obsolete synonym for a Battery of Cells.

Pilot Wire. (*a*) A wire used for measuring the voltage at a distant part of a network.

(*b*) In a multiple-unit system, a wire used between the master controller and a contactor.

Plant. A collective term including various machines, equipment, and apparatus used together for any purpose.

Planté Plates. Accumulator plates prepared by electrolytic action on lead in acid.

Plough. An appliance for effecting a sliding electrical connexion between the conductors of a conduit system and the electric equipment of a car.

Plug Contact. A slightly conical or screwed metal plug for making electrical contact between two conductors, conducting bars or blocks, or between the bars or blocks and the plug.

Point. In wiring. The termination of the wiring for attachment to the fitting for one or more lamps or other consuming devices.

Polarity. A quality of a body in virtue of which certain characteristic properties are manifested at points called Poles.

Polarization. A condition set up in a battery or electrolytic cell as a result of the passage of a current and which manifests itself by a counter electromotive force.

Pole (*a*) of a cell. Synonym for the Terminal or the accessible part of an electrode.

(*b*) of a magnet. Points towards which lines of force converge, or at which the resultant magnetic force may be considered to act.

(*c*) of an arc. The extremity of each of the electrodes between which the arc burns.

Pole-piece. Any specially shaped piece of magnetic material forming a polar extension, and in the case of a generator or motor, facing the armature.

Polyphase. *See* Phase.

Positive. Of the two poles of any source of electricity, that one is called Positive which corresponds as far as the direction of the current in the external circuit is concerned to the copper plate of a Daniell cell.

Potential, Difference of (*a*) **Electric.** A difference of potential exists between any two points if energy is expended or acquired in moving a unit of electricity from one point to the other. In practice measured by a voltmeter.

(*b*) **Magnetic.** A difference of potential exists between any two points if energy is expended or acquired in moving a unit magnetic pole from one point to the other.

Potentiometer. An instrument for measuring electrical quantities depending in principle on balancing an unknown difference of potential against a known fall of potential obtained by the passage of a current through an adjustable resistance.

Power. The rate of doing work. Units, the Watt, Kilowatt, and Horse-power. *See* Watt.

Power Factor. The ratio of the watts to the volt-amperes. In the case of voltage and current of sine form the power factor is cos ϕ.

Practical Units. Some of the units of the centimetre-gramme-second or C.G.S. system are inconveniently large or small for practical purposes, and therefore certain practical units have been chosen, which are made some decimal multiple or sub-multiple of the corresponding units. Thus, the ampere is one-tenth and the volt is one hundred million times the C.G.S. unit (electromagnetic) of current and the C.G.S. unit of electromotive force respectively.

Pressure. Often used as a synonym for Voltage, Electromotive Force, Difference of Potential.

Primary (*a*) **Cell** or **Battery.** *See* Cell, in contradistinction to a secondary battery or an accumulator.

(*b*) of a transformer. That winding of a transformer to which electrical energy is supplied.

Pull-off. *See* Ear.

Pulsating Current or **Pulsatory Current.** A unidirectional current which varies in some periodic or quasi-periodic manner.

Pyrometer. An instrument for measuring temperatures higher than those measurable by an ordinary thermometer.

Quadrant Electrometer. A measuring instrument consisting of a moving vane or needle placed within or near four quadrants, the electrostatic forces between the fixed quadrants and the moving needle producing the deflexion.

Quadruplex Telegraphy. The method in telegraphy in which four messages are sent simultaneously, two in each direction.

Quantity (*a*) of electricity. The product of current and time. Units, Coulomb and Ampere-hour.

(*b*) Obsolete term for the strength of a current as distinguished from the intensity of the battery which furnishes the current.

R.M.S. Abbreviation for root-mean-square.

Rail, Live, Third, Fourth. *See* Conductor Rail.

Rated Load or **Output** (of generators and motors). The output which generators or motors are intended to produce under specified conditions.

Rating of generators, motors, accumulators, etc. The designation of the proposed output under the specified conditions, such as continuous working or intermittent working.

Ratio of Transformer, Ratio of Transformation. The number obtained by dividing the primary volts or amperes by the secondary volts or amperes in voltage and in current transformers respectively. The number is not quite constant, and depends to some extent on the conditions.

Reactance. That component of impedance which is not caused by resistance.

Reactive Current. The component of the current in quadrature with the voltage.

Reactive Power. In an alternating-current circuit, the product obtained by multiplying the volt-amperes into the sine of the angle of phase-difference between the current and the potential difference.

Reactive Voltage. The product of reactance and current.

Receiver, Telephone. That part of the telephone apparatus which reproduces the sounds.

Recorder. Any apparatus which makes a permanent record.

Rectifier. An apparatus which converts an alternating current into a unidirectional current.

Rectify, To. To convert an alternating current into a unidirectional current approaching more or less to a continuous current.

Regulation (*a*) of a generator. The variation (up or down) of pressure between no load and full load under specified conditions.

Special meaning. The percentage rise in pressure when full load is removed from a generator, the speed and excitation being kept constant.

(*b*) of a motor. The variation (up or down) of the speed between no load and full load under specified conditions, usually constant supply voltage.

(*c*) Telegraph and overhead wire-work. The equidistance of wires on a span.

Relay. An apparatus for opening or closing a circuit, controlled by the current in another circuit.

Reluctance. *See* Magnetic Reluctance.

Reluctivity. *See* Magnetic Reluctivity.

Remanence. *See* Magnetic Remanence.

Remote Control. The controlling of apparatus and plant from a distance, *e.g.* the operation of the main switches from a switchboard at a distance from them.

Residual Magnetism. The magnetism remaining after the magnetizing force has been removed.

Resistance. (*a*) That property of a substance or body which causes in it a dissipation of electrical energy as heat when a current flows through it.

(*b*) The resistance of a conductor is the quotient of the potential difference between the terminals of the conductor by the current, usually expressed in ohms.

Resistance, Magnetic. *See* Magnetic Reluctance.

Resistance, Specific. *See* Resistivity.

Resistivity. The resistivity (specific resistance) of a substance is the reciprocal of the Conductivity.

Resonance. A circuit is said to be in resonance when the oscillations produced in it have the frequency of the natural oscillations in the circuit.

Retentivity. A synonym for Coercive Force.

Return Feeder. In electric traction. The conductor conveying electric current from the rails to sub-stations or to the generating station.

Reverse Current Breaker. A circuit breaker which is opened automatically when the direction of the current is reversed.

Reverse Current Relay. A relay which is only operated by a current in one direction.

Rheostat. A readily adjustable resistance.

Rotary Converter. *See* Converter.

Rotor. That part of an alternating-current generator or motor, whether armature or field magnet, which rotates.

Ruhmkorff Coil. A kind of transformer used for producing high electromotive forces, consisting of a primary and a secondary winding on a straight core. The primary is supplied with a continuous current which is periodically interrupted.

Running Light (of a generator, converter, or transformer). Running when no appreciable current is delivered to the external circuit.

(of a motor). Running when no power is delivered at the shaft.

Safety, Factor of. *See* Factor.

Sag of a wire. The maximum vertical distance between a wire and the straight line joining the points from which it is suspended.

Secondary of a transformer. *See* Secondary Winding.

Secondary Battery. *See* Accumulator.

Secondary Winding of a transformer. The winding in which the electromotive force is generated by electromagnetic induction and from which electrical energy is supplied to the external circuit.

Section Insulator. An insulator by means of which a conductor is divided electrically into sections while maintaining mechanical continuity.

Section Switch. A switch for electrical disconnexion of a circuit into sections.

Selector Switch. A switch for connecting a circuit to any one of a number of other circuits.

Self-induction, Coefficient of. *See* Induction, Self-.

Sensibility or **Sensitivity.** *See* Figure of Merit.

Series. Two or more conductors are said to be in series when they are so connected that they are traversed by the same current.

Series Dynamo. A dynamo in which the field magnet coils are in series with the armature.

Series Parallel. (*a*) A number of pieces of apparatus are connected in Parallel and the groups so formed are connected in Series.

(*b*) A number of pieces of apparatus are connected in Series and the groups so formed are connected in Parallel. In U.S. it is common to call (*b*) Parallel Series in order to distinguish it from (*a*).

Series-Parallel Connexion. Pieces of apparatus are connected either in series or parallel with arrangements for changing over from one set of connexions to the other.

Series-Parallel Controller. A device for making Series-Parallel Connexion.

Short. A colloquial abbreviation for a Short-circuit or for the act of making a Short-circuit.

Short-circuit. A connexion, whether accidental or intentional, between two points in a circuit, by means of a path having a low resistance.

Short-circuited Rotor. A rotor which is short-circuited in itself. *See* Squirrel-cage.

Shoe. An appliance for effecting a sliding connexion between a conductor rail of an electric railway and the electrical equipment of a car.

Shunt. (*a*) Circuits are said to be in shunt or in parallel one to the other when a current is divided between them.

(*b*) A by-path for an electric current.

(*c*) Shunt circuit is a term applied to the pressure circuit of measuring instruments such as electricity energy meters, wattmeters, etc.

(*d*) A current shunt is a term applied to a low resistance used for the measurement of currents by means of a potentiometer; or by an ammeter through which only a fraction of the current passes.

Shunt Coil or **Winding.** A coil or winding which is connected in shunt or parallel to some part of the circuit.

In a generator or motor. The field magnet coils of a shunt dynamo or motor, these coils being excited by a current practically proportional to the pressure.

Shunt Dynamo. A dynamo in which the field magnet coils are connected to the terminals in shunt.

Shunt Instrument. An instrument in which all but a fraction of the current to be measured is passed through a resistance connected in parallel with the measuring instrument.

Shunt Motor. A motor in which the field magnet coils are connected to the terminals in shunt.

Shuttle or **Siemens Armature.** An early form of armature for a generator or motor, resembling a shuttle, and having a single coil and two core faces. Sometimes called an **H** armature.

Siemens Dynamometer. An instrument for measuring currents, either continuous or alternating, consisting of a fixed coil and a suspended coil controlled by a spring, the torsion of the spring being proportional to the square of the current when the coils are brought back to their initial relative positions.

Siemens Unit of Resistance. The resistance of a column of mercury of a sectional area of one square millimetre and of a length of one metre, at 0° C.

Silver Voltameter. An apparatus for measuring a quantity of electricity by the weight of silver deposited on a platinum kathode from a solution of silver nitrate.

Simplex. A method of telegraphic working in which only a single message is transmitted at one time.

Single-phase. *See* Phase.

Single-Pole Switch. A switch which opens a circuit at one point only.

Siphon Recorder. An apparatus used in submarine telegraphy consisting of a magnetic field in which a

moving coil makes a record of the signals by means of a siphon acting as a pen.

Skate. An appliance for effecting a sliding electrical connexion between the studs of a surface contact system and the electrical equipment of a car.

Slide Wire. In a measuring instrument a wire of uniform resistance on which a sliding contact makes connexion at any desired point.

Slip. In an induction motor the angular velocity of the rotor is less than that of the rotating magnetic field of the stator, and this difference expressed as a fraction of percentage of the angular velocity of the rotating magnetic field is called the slip. The use of the word Slip to express the mere difference of angular velocities is not recommended.

Slipper Brake. A brake in which a block or slipper is pressed against the rails of a tramway. Also called a Track Brake.

Slip-ring. A conducting ring for effecting, by means of a brush, a sliding connexion between a revolving conductor and a fixed conductor. *See* Collector ring.

Slot System. *See* Conduit System for traction.

Slotted Core. An armature core of a generator or motor having slots in the iron in which conductors are placed.

Smooth Core. An armature core of a generator or motor on the surface of which conductors are laid.

Socket, Lamp-. Synonym for Lampholder.

Solenoid. A coil of tubular form for producing a magnetic field.

Sole Plate (tramway). A plate or piece of rail fastened below a rail joint for strengthening and anchoring it.

Sounder. A telegraphic receiving instrument producing audible signals.

Spacing Current. In telegraphy a current used to produce the space between the signals, flowing generally in the reverse direction to the signalling currents.

Span Wire Construction. A mode of supporting a trolley wire by transverse span wires stretched between poles or buildings.

Spark (electrical). A disruptive discharge of electricity through a dielectric.

Spark-gap. Any break in the continuity of a conductor so arranged as to permit of a disruptive discharge across the break.

Specific. Pertaining to or characteristic of a substance; *e.g.* the specific resistance of a given material is the resistance between the opposite faces of a cube of that material whose edge is one centimetre.

Squirrel-cage. A winding used on induction motors which consists of a number of bars, the ends of which are short-circuited.

Standard (noun). A thing serving as a basis of comparison. Such as a weight or measure to which others conform or by which the accuracy of other weights or measures is judged. *See* also Unit.

Standard Candle. Formerly used in photometry. A sperm candle weighing one-sixth of a pound, intended to burn 120 grains per hour.

Standard Candle (International). Unit of light. One-tenth of the light given horizontally by the Standard Ten-candle Pentane lamp under specified conditions.

In U.S. the Standard is maintained through the medium of a group of selected incandescent lamps at the Bureau of Standards in Washington.

Standards, Electrical. British Board of Trade. *See* also Units, International. Resistance, the one-ohm coil of wire. Current, the one-ampere balance. Potential difference, the 100-volt electrometer.

Standard Lamp (electrical fittings). A lamp to stand on a table or floor. Lamp-standard, a pillar supporting a street lamp.

Star. A mode of connexion in polyphase alternating-current working, in which three or more conductors meet at a common junction called the neutral point. When there are only three conductors, also called a **Y** connexion.

Static. (1) Pertaining to electricity at rest. Abbreviation for Electrostatic. (2) Sometimes applied to a transformer, to distinguish it from a converter. Not recommended.

Stator. In an alternating-current generator or motor, the winding and associated iron, whether acting as armature or as field magnet, which does not rotate.

Storage Battery. *See* Accumulator.

Striæ. In an electric discharge through a gas, alternate dark and luminous transverse bands.

Stud (tramway). A piece of metal or apparatus from which the current is collected, laid down in the street between the rails of a surface-contact system of traction.

Sub-station. Officially defined in Great Britain as premises in which electrical energy is transformed or converted for the purpose of supply to consumers, if such premises are large enough to admit the entrance of a person after the transforming or converting apparatus is in position. (Thus distinguishing it from a Transformer Box or Chamber.)

Sulphate, of an accumulator. In a lead accumulator the formation on the plates of a sulphate of lead which is inactive and hinders the action of the Cell.

Surface Contact System. A tramway system in which studs normally dead, placed between the rails, become connected to a main only when a car passes over them.

Surge. An abnormal rush of electricity along a conductor.

Surge-impedance. The natural impedance of any long conductor to transmit electric currents or surges, $=\sqrt{L/C}$.

Susceptibility. *See* Magnetic Susceptibility.

Suspension Wire (Telegraph). Synonym for Messenger Wire.

Switchboard. An assemblage of switches, fuses, conductors, measuring instruments, and other apparatus for the control of electrical machinery and circuits.

Switch Hook (Telephone). The hook on which a receiver is hung. When the receiver is placed on the hook its weight performs certain switching operations.

Synchronism. Two machines are said to be in synchronism when they are running on one system with identical frequency and a definite phase relation.

Synchronize, To. To cause two or more machines or pieces of apparatus to have the same periodic time or frequency and a definite phase relation.

Synchronous Motor. An alternating-current motor which normally runs at the speed corresponding to synchronism with the supply.

Synchronoscope. An apparatus intended to indicate

when two alternating potential differences are in synchronism and in phase.

Syntonize. To adjust to the same periodic time or frequency. In wireless telegraphy called to Tune.

Syphon Recorder. *See* Siphon Recorder.

Tandem. *See* Cascade.

Tapper (Wireless). An apparatus which taps a coherer and automatically decoheres it after the receipt of a signal.

Telegraph. An apparatus for transmitting messages to a distance by means of signals.

Telegraph Line. *See* Line.

Telephone. An apparatus for transmitting sound to a distance.

Telpherage. A system for the electrical transport of goods or materials in self-contained motor-driven receptacles suspended from, and running on, stretched wires.

Temperature Coefficient. The change in the magnitude of any property of a substance caused by a rise of one degree Centigrade in the temperature, expressed as a fraction of the magnitude at some definite temperature adopted as a standard.

Temperature Rise. Of electrical machinery. The increase of temperature of any part of an electrical machine above the temperature of the surrounding atmosphere.

Tension. A synonym for Electromotive Force or Difference of Potential. Obsolete term when used alone.

Tension, High. Synonym sometimes used for High Voltage, or High Pressure. Abbreviation H.T. (Board of Trade limits, 650 to 3,000 volts, whether continuous or alternating.)

Tension, Extra High. Synonym sometimes used for Extra High Voltage or Pressure. Abbreviation E.H.T. (Board of Trade limit, above 3,000 volts, whether continuous or alternating.)

Terminal. That part of an apparatus or circuit to which conductors are intended to be joined in order to connect it electrically to another apparatus or circuit.

Terminal Voltage. *See* Difference of Potential at the Terminals.

Thermo-couple. A pair of conductors joined to produce a Thermo-electric Effect.

Thermo-electric Effect. The electrical effect due to a difference of temperature between two junctions. Sometimes called Seebeck Effect.

Thermo-pile. Apparatus consisting of thermo-couples suitably arranged.

Third Rail. *See* Conductor Rail.

Thomson Effect. (*a*) The electrical effect due to a difference of temperature between two parts of one and the same conductor; (*b*) the liberation (or absorption) of heat which takes place when current flows from a hotter to a colder portion of the same metal.

Three-phase. *See* Phase.

Three-phase Transformer. A transformer in which three magnetic circuits have parts in common with one another.

Three-wire System. A system of supply through three wires, in which the potential of the middle wire is intermediate between those of the outer conductors.

Time-constant. When the rate at which a function is diminishing equals the function multiplied by a constant quantity, the reciprocal of this quantity is called the time-constant. It is equal to the time taken by the function to fall to $1/\epsilon$, that is, 36·8 per cent of its initial value.

Total Loss. The difference between input and output.

Transformer. An apparatus without moving parts which by means of electromagnetic induction transforms alternating voltages into alternating voltages of the same frequency, but generally of different magnitude.

Transformer Box or **Chamber**. A box or chamber containing a transformer and not large enough to admit the entrance of a person after the transformer is in position. (Thus distinguishing it from a Sub-station.)

Transformer, Core Type. A transformer with a closed magnetic circuit in which the copper windings completely or almost completely enclose the iron core.

Transformer, Primary of. *See* Primary.

Transformer, Secondary of. *See* Secondary.

Transformer, Shell Type. A transformer with a closed magnetic circuit in which the magnetic circuit completely or almost completely encloses the copper windings.

Translator. A form of telegraphic relay. Also called a Repeater.

Transmitter. That part of a telegraphic or telephonic apparatus by which signals are sent.

Trolley System. A traction system employing cars on each of which is mounted a standard carrying a boom. At the end of the boom is fixed a swivelling trolley head containing a trolley wheel which runs on the trolley wire. When the car is single-decked or has a roof over the upper deck the boom is carried on a base.

Trunk Main (*a*) in electrical supply. A main used as a feeder between a generating station and a substation or between two generating stations.

(*b*) in telegraphy and telephony. A line consisting of numerous circuits connecting two or more towns or exchange areas.

Tube of Force (Electrostatic Faraday Tube). The unit tube of force is bounded laterally by lines of force which enclose unit charges at its ends. It therefore contains 4π lines of flux.

Tune, To (wireless telegraphy). To adjust to a given periodic time of frequency.

Turns, Ampere-. *See* Ampere-turn.

Two-phase System. *See* Phase.

Two-phase Transformer. A transformer for two-phase currents, in which two magnetic circuits have parts in common with one another.

Unifilar Suspension. The suspension of the moving part of an instrument by a single thread or wire or strip, the restoring force being produced by its torsion.

Unipolar. *See* Homopolar.

Unit (physical). A selected definite physical quantity in terms of which the magnitudes of other physical quantities of a like kind may be reckoned or expressed.

C.G.S. system of units. A system employing the centimetre, the gramme, and the second as the fundamental units.

Electromagnetic primary Units. 1. Unit of Resistance. 2. Unit of Current. 3. Unit of Difference of Potential.

Derived Units. Quantity, Capacity, Self-induction.

Practical Units. *See* Practical Units.

International Units. The Ohm, Ampere, Volt, and Watt.

Board of Trade Unit. One Kilowatt-hour or Kelvin.

Virtual Ampere. The alternating current which produces the same heating effect as one ampere continuous current. The root-mean-square of the current, sometimes called Effective Ampere. A term not recommended.

Virtual Volt. The alternating electrical pressure which when applied to a non-inductive resistance of one ohm produces one virtual ampere. The root-mean-square of the volts. Sometimes called an Effective Volt. A term not recommended.

Volt. (*a*) The electrical pressure which when applied steadily to a conductor the resistance of which is one ohm, produces a current of one ampere.

(*b*) 10^8 C.G.S. electromagnetic units of Electromotive Force.

Voltage. Synonym for Electromotive Force, Difference of Potential and Pressure. Generally used descriptively.

Voltaic Current. An electric current produced by chemical action.

Voltameter. An electrolytic cell arranged for the purpose of measuring an electric current by determining the amount of chemical action produced.

Voltmeter. A measuring instrument with its scale graduated in volts for measuring electromotive force.

Wall Plug. An appliance containing both of the terminals of a twin flexible conductor, generally in the form of two pins (two-pin plug) or a pin and a concentric ring (concentric plug) which, when it is inserted in a wall socket, makes connexion between the flexible conductors and the fixed leads.

Wall Socket or **Shoe**. An appliance fixed to the wall into which are brought both the leads or conductors connected to a source of supply so that connexion may be made by inserting a wall plug.

Watt. Unit of Power. The energy expended per second by an unvarying current of one ampere under an electric pressure of one volt. With alternating current, the product of the instantaneous amperes into the instantaneous volts gives the instantaneous value of the power. The mean value of this over a whole period is the power in watts. It is equal to 10^7 ergs per second or 1 joule per second. *See* Kilowatt.

Watt-hour. The total energy expended when electrical energy is expended at the rate of one watt for one hour, or its equivalent, such as 4 watts for 15 minutes. Equal to 3,600 joules.

Watt-hour Meter. An integrating meter for measuring watt-hours. Also called an Energy Meter. The use of the term wattmeter in this connexion is strongly discouraged.

Wattless. When the phase difference between the current and the applied voltage is 90 degrees, the current is said to be Wattless or Reactive. In U.S. a term used by some, but strongly disapproved of by many.

Wattmeter. An instrument with a scale graduated in watts for measuring electrical power.

Weston Cell. A mercury, cadmium-sulphate, cadmium amalgam cell, prepared according to a certain specification, used as a standard of potential difference.

Wheatstone Bridge. A particular arrangement of resistance, galvanometer, and battery as an instrument for the comparison of resistances.

Wheel Base (railway or tramway). The distance between the points of contact of successive wheels of a vehicle with the rails.

Windage. The friction of the air on moving parts of machinery and vehicles.

Winding. All the conductors, turns, or coils belonging to one system.

Yoke. The iron connecting piece between the ends of the core or cores of an electromagnet, which is outside the windings.

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ELECTRIFICATION OF RAILWAYS AS AFFECTED BY TRAFFIC CONSIDERATIONS.

By H. W. Firth, Member.

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The application of electric traction to any extensive section of any of the large trunk lines of this country is a problem of great complexity. The technical aspects of electric traction from the electrical engineer's point of view have been considered fairly fully both by this Institution and by other engineering societies, but the consideration of traffic questions has not had the attention that it merits.

The electrification of a tube line, or similar property where the whole of the business is of one character, is comparatively simple; but the traffic problems which have to be considered in the case of trunk lines—problems almost, if not entirely, independent of the system of electric traction adopted—are complex and not easy to solve.

The main difficulty arises from the fact that traffics of widely varying character have to be handled over the same rails. The business of a great railway does not consist merely in passenger transportation, but comprises numerous services all of which must be performed as economically and expeditiously as possible, and some of which are more or less conflicting.

There is not only the working of goods trains involving shunting and marshalling, and requiring to be handled over the same roads as passenger services, but there is a very great diversity in passenger business alone. There are :—

1. Ordinary suburban trains, mostly consisting of trains running backwards and forwards on one particular trip regularly.
2. Less-frequent local trains performing journeys to the outer suburban area distant up to, say, 50 miles from the terminus.
3. Main-line express trains making long non-stop runs.
4. Main-line slow trains handling a large amount of parcels and milk traffic in addition to passengers.
5. Special horse-box trains and empty carriage trains.
6. Other varieties of traffic.

All these various classes of trains have to be accommodated on the same line in many cases, and the matter is still further complicated by the fact that in most instances there are branch lines, more or less numerous, having to be served as regards goods, passenger, parcels, horse-box, and other traffic.

The working is rendered more difficult in some cases by being largely seasonal. In the summer-time the seaside or other holiday expresses are more numerous. In some instances the time of maximum pressure of this traffic occurs at or about the same time as that of maximum pressure of suburban business. For London termini, at any rate, it is an important point, and the conjunction of the two maxima, notably about 12.30 p.m. to 1.30 p.m. or 2 p.m. on Saturdays, considerably increases the difficulties.

There are few termini—in London at all events—where sufficient room is available for carriage storage to any large extent, and consequently carriage stock has to be kept at sidings some way out, so that for these holiday expresses (and for other passenger services also) an empty-carriage train has to be run from or to sidings, to or from the terminus as the case may be.

A main-line train also requires more time than others for loading luggage, mails, bicycles, etc., and therefore occupies the platform for a greater length of time than a suburban train.

Operation of Trains on Different Services.

A difficulty experienced in the case of local traffic is the fact that rolling stock cannot always be reserved for one service only. A train may have to operate on one trip as a slow train, calling at stations the average distance apart of which is less than one mile, and it may be desirable on other trips to run the same train at a higher maximum speed for considerable non-stop runs.

The widely varying speed characteristics of these ser-

vices render it necessary to give very careful consideration to the motor characteristics and gear ratio, and the author would suggest that the attainment of a more flexible speed characteristic of the motor, either by partially shunting the series field of the ordinary series motor as has been suggested, or by some other means such as separate field control, is very desirable. The former method has been to some extent used, but the latter does not appear to have received the attention from designers which in the opinion of the author it deserves. Mr. R. T. Smith in his recent paper to this Institution * has also drawn attention to this matter as affecting electric locomotive design.

This question of the use of rolling stock in different services is a very important matter for lines having both a heavy suburban business and also a heavy seaside excursion traffic. On summer Sundays and Bank Holidays when the suburban business is greatly reduced, the seaside excursion trains are largely formed by suburban stock, in the first place in order to economize stock generally, and secondly because the great seating capacity of suburban stock lends itself to the satisfactory carrying of such traffic. On some railways the mileage thus run by suburban stock in non-suburban trips is as large as 80,000 or 100,000 miles per annum. Under steam conditions this flexibility in the user of rolling stock is of course easily attained, and any kind of carriage can be handled by any kind of locomotive.

To electrify the whole of the suburban trains may therefore necessitate the provision of spare stock for such trips as those mentioned above, unless the more important sections of the seaside traffic nearest to London are themselves electrified.

The nearer seaside resorts—those 50 or 60 miles from London—are becoming increasingly popular as residential neighbourhoods for London business men, and a large residential traffic is being built up. The conditions mentioned above may in the author's opinion have some weight in causing the electrification of such seaside traffic to be considered.

There are consequently very considerable difficulties owing to the above-mentioned conditions—which are of course merely the routine of railway working—in the provision of adequate accommodation for all classes of traffic at the "rush hours," and the problem is very different from that of handling urban or suburban passenger traffic pure and simple.

The general electrification of long-distance main-line passenger and goods trains has not yet been seriously considered in this country, and in the author's opinion the problem is not at the moment pressing. Under present conditions as to cost of steam and electric working for these particular services, the advantages to be gained by general electrification are apparently not commensurate with the capital expenditure necessary.

It may well be in certain special cases that the electric working of heavy mineral or other traffic over severe gradients will be economically justified, and the electrification of the Shildon section of the North-Eastern Railway where a very heavy mineral traffic is handled may be the forerunner of many similar instances, although, as Mr. Aspinall and Mr. R. T. Smith have pointed out, the possibility of handling heavier goods trains in this country is considerably limited by the strength of the couplings of traders' wagons.

Whatever the future may bring in this way, the heavy inner suburban and outer suburban passenger traffic in the neighbourhood of London, and the suburban and interurban business round other great towns, are at present the main subjects for consideration of those now studying the electrification of steam lines.

Definition of "Inner Suburban," "Outer Suburban," and "Main Line" Passenger Services.

There is no hard and fast line of demarcation between these services. A "slow main-line" train may, in the course of a journey of, say, 100 miles, deal with all three kinds of traffic. It is, however, desirable to obtain some basis of description which may be generally used. The term "main-line services" has been used by different authors and speakers for totally different things. The present author is of opinion that the term "main-line traffic" or "main-line service" should be strictly limited to those services serving widely scattered communities quite distinct from each other and having no regular, all-the-year-round, residential, social, or amusement, traffic.

To speak of such services as London–Brighton, London–Clacton, London–Southend as "main-line" is not in the author's opinion correct. They are all services which have—or can be made to have—the characteristics of suburban traffic, *i.e.* a large season-ticket residential business with a flow of traffic largely "up" in the morning and "down" in the evening.

Such services, as has been proved by the three examples given, can even under steam conditions be made to attract large numbers of people, the present tendency being to live further away from town, and particularly so when seaside resorts can be reached comfortably in a journey of, say, under two hours. On the other hand, no augmentation of train service or reduction of fares will induce daily residential travel as between London and, say, Liverpool or York. Mere distance, although an important factor, does not necessarily make any particular service a main-line service from the traffic character point of view. The point that the author would emphasize is that it is the *character* of the traffic which is of importance, not merely the distance.

The author considers that the true main-line business, as above defined, cannot be profitably electrified at present except under exceptional circumstances, but the outer suburban traffic must be carefully considered whatever its length of run, because in many cases there may be great possibilities of obtaining by electrical means a considerably increased revenue, apart from the residential regular daily business, at comparatively small extra cost, especially in the case of seaside resorts with considerable traffic "down" in the morning and "up" in the evening.

It may be of use to state again the outstanding characteristics of steam as against electric operation of trains generally.

Steam traction can handle efficiently and at reasonably low costs, both for operation and fixed charges, a train service of heavy trains even at fairly short headway with stops not very close together. With few stops and an irre-

* R. T. Smith. Some railway conditions governing electrification. *Journal I.E.E.*, vol. 52, p. 293, 1914.

gular and infrequent train service electric traction cannot show much superiority in operating characteristics; but if the stops are at short distances apart or the service demands great flexibility in seating capacity to meet widely varying passenger numbers, the operating conditions then demand two features which electric traction can give :—

(1) High acceleration.
(2) Multiple-unit train formation.

Where the operating conditions, *i.e.* the requirements of traffic, are such as to make these demands, electric traction is the proper means of adequately meeting these requirements, and it then remains to investigate the financial aspects of the change.

Formation of Trains and the Effect on Electric Working.

Under present conditions not only do the trains on one branch or portion of a system differ in make-up from those on another, but frequently almost every individual train will have a particular formation. Some trains must have dining-car sets, and some must have more than the usual number of brake vans as they deal with special traffic such as mails or milk. The result is that the particular vehicles forming an "up" train due in a terminus at say 4 p.m., most likely cannot form, as might be thought, the 4.30 p.m. "down" train to some other point, even if up to time, as its formation is not suited to the particular requirements. Consequently it has to run out to the car sidings as empty cars, and return to the terminus also as empty cars at some other time for a "down" journey suitable to its formation, or else it has to be split up and re-formed at the car sidings.

There are three results from this :—

1. Low mileage of vehicles in profitable work.
2. Considerable light (unprofitable) mileage and cost of haulage.
3. In congested terminal districts very serious occupation of the limited line accommodation by non-paying car trains to the exclusion of paying passenger trains.

If electrification of this class of traffic takes place, the situation is—financially—more serious. While it is obviously undesirable not to obtain the fullest possible mileage from every car even now, it is impossible to consider installing expensive electric equipment on cars so utilized for only a fraction of the possible time. The use of electric locomotives instead of multiple-unit equipments may be suggested as a remedy for this, but many of the extra suburban services—to places 40 or 50 miles distant—really call for multiple-unit working if the full operating advantages of the electrification of these services—particularly at crowded termini—are to be reaped.

The requirements of different trains, the provision on certain trains of through carriages to different branches, and other similar train-formation problems, are responsible not only for a very low mileage of rolling stock, which implies a very costly equipment of rolling stock for a given seat mileage per annum, but also—and perhaps more important still—for congesting the terminal area with carriage trains which not only cost money to haul backwards and forwards but also prevent the running of paying trains.

The problem of improving this feature of working is not easy of solution, but it is in the author's opinion worth a great deal of study even under present steam conditions, and in some electrification projects may be of almost vital importance. The number of car trains between the terminus and the car sidings compared with the number of passenger main-line trains may be some 80 per cent, *i.e.* if all carriage-train working could be eliminated this section of line could handle 80 per cent more passenger-carrying trains. The solution, if one be possible, must be looked for in two directions :—

1. Standardizing the trains on different services as much as possible.
2. A bold re-timing of trains to eliminate a good proportion of carriage-train working.

Re-timing of suburban trains (using the term "suburban" in its broadest sense of daily season-ticket travel irrespective of distance) is not easy, as the exigencies of business demand the arrival in town of large numbers of people at a more or less fixed time. More flexibility of timing of purely main-line trains can be allowed, but any alteration affects branch services and connections all down the line; although the use of train diagrams enables the whole service to be viewed quickly, the re-timing of the general traffic of an important line is not one to be lightly undertaken.

Bunching of Trains.

When once a clear track has been arranged all down the run for an express train leaving a terminus or starting-point at a given time, it is far easier to let two or three more similar expresses follow at a few minutes' interval than to arrange for a similar clear track some time later. There is therefore a tendency—largely for good and sufficient reasons—to run main-line trains in bunches, *i.e.* four or five trains at a few minutes' interval and then none for some time. This leaves the required intervals for pick-up passenger and slow goods trains. Under steam conditions this involves no operating drawbacks as far as the main-line run is concerned, but under electric conditions it would be very bad. Even under steam conditions, however, when we come to terminal working the practice results in giving a bad platform load factor. The re-timing of such bunches of trains would not only relieve the terminal working, but give an improved service of greater regularity to main-line points.

The possibility of such re-timing depends largely on the lay-out of sidings and avoiding tracks where goods or slow passenger trains can be shunted to enable expresses to pass. In the ordinary way a lay-by siding is arranged as a trailing-point connection to the running line. To slow up and then stop a long, heavy, goods train, and then shunt it back into the siding until the engine is clear of the trap points may take as much as 8 or 10 minutes. To enable main-line traffic to be re-timed, many such sidings may have to be converted to facing point sidings, an alteration which it is not always possible to carry out.

User of Platforms.

A suburban train can arrive at and depart from any one of a number of platforms, and no difficulty therefore

arises in making an incoming train serve as an outgoing train from the same platform; but with main-line trains the conditions are different. As far as possible important main-line trains must arrive at one of a number of special arrival platforms, alongside, or very near to, cab roads, and cannot easily again be dispatched from the same platform as a "down" passenger train as it is necessary to deal with various requirements, such as the cleaning of the train, the re-stocking and cleaning of dining-cars, and the filling of gas and water tanks. Unless, therefore, the number of platforms is large, compared with the number of entrance roads, so that a considerable time can be allowed in platforms, a considerable mileage of carriage-train working is necessary.

Limit of Electric Zone.

The fixing of the limit of the zone in which electric working is to supplant steam traction involves both technical electrical questions and traffic considerations. From the latter standpoint—which is the one that the author is more particularly dealing with in the present paper—it includes the further question of what classes of traffic shall be electrically worked, as well as the distance over which electric working is to take place.

If any satisfactory results from a traffic point of view are to be obtained by electric traction, it appears imperative to electrify at any rate all suburban and local passenger traffic (with the possible exception of some "rush hour" steam trains as mentioned below) within a certain zone in order to standardize the acceleration and schedule speed of these classes of traffic and thus get by uniformity the greatest capacity out of a given line, although it may appear in studying a complicated suburban electrification scheme that some of the smaller services are not sufficiently important or remunerative to warrant electrification from the point of view of the increased revenue possible.

Provided some satisfactory system can be adopted of so sectionalizing the traffic as to ensure at any rate at "rush hours" that traffic on a given line is almost, if not quite, all of the same character as regards acceleration and schedule speed, there seems no good reason at the moment to anticipate the electrification of the main-line business in the congested area. Where, however, it is impossible to prevent a general intermingling of traffic of varying speed characteristics in the densely crowded area, it may be necessary to consider what may be termed terminal electrification, *i.e.* the electric handling of all traffic, whether goods, main-line passenger, or suburban passenger, within a certain zone.

Such a case is very well illustrated by the New York Central Railroad, who have adopted the policy of electrifying all traffic in the congested terminal area.

Signalling.

On a line where all the traffic is of much the same character, where the rates of acceleration and braking are of the same order, and the length of the train unit is fairly regular, a service of trains at very close intervals can be maintained and the block signalling can be designed very closely for the conditions. On stretches of line, however, which have to accommodate at various times high-speed expresses of perhaps 450 tons at 60 or 70 miles per hour, long heavy goods trains 380 or 400 yards in length, or light suburban or local trains of only a few coaches, the block sections must be so proportioned as to give ample distance, having regard to gradients, curves, junctions, and other features, for the pulling up of the longest and heaviest trains.

As a paper on Electric Signalling has recently been read before the Institution by Mr. H. G. Brown* it is here proposed only to draw attention to some of the more general points in this connection.

Although in parts of the more densely crowded systems the lines are usually doubled or trebled it is a matter of the greatest difficulty to sectionalize the traffic, and although it is possible to some extent to allocate certain lines to certain traffic—some lines for suburban or slow passenger trains, some for fast passenger trains, and some for goods—it is necessary that any line may be capable at any time of receiving the traffic of another line which may be temporarily blocked. Again, the suburban business of at any rate some of the biggest suburban traffic-carrying lines entering London has a comparatively bad load factor. The suburban traffic on the steam lines entering London is very largely a dormitory traffic, heavy "up" traffic for two or three hours in the morning and heavy "down" traffic for two or three hours in the evening, with the worst rush for a very short time on Saturdays between 1 p.m. and 2.30 p.m. or 3 p.m., and consequently suburban traffic overflows to other adjacent main or local lines.

In this connection it may be remarked that the recent Shop Hours Act has added quite appreciably to the troubles of some railway companies by causing a much more general closing of business premises at 1 p.m. on Saturdays, and thus accentuating a peak load with which it was already not easy to deal.

This being so, it is obviously not possible in general to allocate a given line to suburban working pure and simple, and to signal it so that this type of traffic alone shall be accommodated; consequently, even if the lines can be sectionalized so as to keep the varying traffics more or less apart, the lines allocated to suburban business must still be so signalled as to be capable of accommodating other trains.

The shortening of sections is, however, not always so important as the elimination of flat junctions and complicated crossings, and if something can be done in this latter respect a very considerable suburban service can be run (especially where long suburban trains are required for the traffic) while still having signalling capable of passing other kinds of traffic when the suburban rush is over.

The minimum length of block sections is primarily dependent on the distance required for braking, plus a constant (equal to the length of the train), and assuming a length of line not complicated by curves, junctions, etc., the length of block sections will vary as the square of the speed of the trains. Comparing speeds of say 60 miles per hour and 30 miles per hour, in the latter case it is possible to cut up the line into four times as many block sections as in the former case, subject to the constant for the length of train, while the running time for each section is one half. It therefore follows that the frequency of trains is doubled. So that if one can restrict the speed to 30 miles per hour instead of 60 miles per hour, one can

* *Journal I.E.E.*, vol. 52, p. 545, 1914.

nearly double the carrying capacity of a line per unit time at a corresponding sacrifice of the schedule speed.

This may operate in an important way in the case of electrification of a railway where the main-line and suburban passenger trains have to run over the same metals for part of the journey. In many cases such lines near the terminal area are signalled for express speeds, while such speeds cannot be consistently maintained by the main-line trains at busy times owing to the intermingling of suburban trains of lower speed characteristics. The average speed of these main-line trains is therefore in practice not as high as the signalling is capable of allowing for, and the block sections are therefore unnecessarily long.

In the author's opinion there are many lines carrying a dense service of trains of varying speed characteristics over sections originally signalled for high speeds where a speed limit of say 30 or 40 miles per hour on main-line trains would enable a much greater frequency of trains to be operated without reducing the average speed of these main-line trains by more than a small amount.

The same question of the proper adjustment of the length of the block section and the speed of trains applies in cases where two lines converge into one. If properly signalled and graded as to speeds, one line in the busy section where speeds cannot be high may adequately feed two branching sections of line in the outlying area where speeds can be high.

Although these principles are to some extent applied on existing lines, the important benefits of careful and scientific grading of speed have not, so far as the author is aware, been utilized to the full extent, and could in many cases be applied so as materially to increase the capacity of the present lines whether electrically or steam operated.

Effect of Crossings and Flat Junctions on Frequency of Service.

One of the most usual difficulties in a general suburban service over a complicated line is the delay of a train at a junction or cross-over from one line to another, and the length of time taken on re-starting to clear the junction or cross-over points. The effect which the high acceleration of an electric train has on shortening the time of crossing, and thus facilitating the clearance of roads for other conflicting trains, is important, but the delay to traffic even in this case is serious.

If the traffic characteristics of any of our big suburban systems be investigated, it will be found that a very large part of the difficulty in getting the trains through, or in getting more trains through, lies in the number of complex junctions and cross-over roads over which the trains serving widely branching systems have usually to run, thus conflicting with other trains.

The number of trains which can be worked over a flat junction depends on many variables, on the speed and length of trains, on the curves and gradients of the converging lines, and on the proportion of the total trains which diverge and therefore cut other trains. As it is difficult to find two junctions where the conditions are the same, every junction must be studied separately in order to arrive at the "junction factor," which is the relation between the number of trains per hour that can be run over the flat junction and the number possible on a plain road. The fewer the number of trains diverging at the junction in proportion to the total number, the higher the junction factor ; but it may be taken that this factor with a fair proportion of splitting of train services on to the two legs of the junction is very rarely as high as 0·8, and in general is more of the order of 0·75. Although a greater service can be worked electrically over such junctions than is possible with steam, the introduction of even one such junction may reduce the capacity of the line, while if many such junctions are present close together the reduction of capacity is almost certain to be serious. In serious cases of complication it will be found that the additional number of trains which can be run even electrically is reduced greatly as compared with the number possible on the plain portions of the line, and often so reduced as to prevent the attainment of an improved service commensurate with the outlay on electrification.

Some lines, like the Great Northern and the London & South-Western, are fortunate in having many flying junctions by which much confliction of trains is avoided, and in these cases the increased train frequency possible with electric traction, owing to superior acceleration, can be taken full advantage of as the "junction factor" of a flying junction is unity, and what is equally important the length of train can therefore be kept within reasonable limits. Where mixed traffic has to be worked over flat junctions it is not possible to have so high a frequency, hence the size of train unit must be increased.

Unfortunately the majority of big terminal systems have grown up gradually, and have developed in ways somewhat unexpected when the lines were originally designed. Additional branches have been connected to the lines, and these connections have in a great number—in fact, in the majority—of cases been laid out as flat junctions where the trains must conflict.

It is futile to spend large sums of money on electrification unless a proportionate increase in service capacity is attained, and in the author's opinion there are numerous cases where electric traction can only be introduced to give its best advantages and to be an economic success if steps be taken to simplify some of these conflicting junctions by means of fly-over lines.

This is particularly the case where trains of different speed characteristics conflict, as where main-line and suburban services have to be intermingled. As a case in point, the electrification of the London & North-Western line has led to the introduction of a burrowing line at Chalk Farm in order to avoid the crossing of Broad-street–Watford trains with Euston main-line services. The amount of work carried out by the District Railway at Earl's Court and elsewhere is also well known. It has also recently been reported in the Press that the London & South-Western Railway is considering the provision of a fly-over between Vauxhall and Waterloo in order to prevent the suburban electric trains intermingling with main-line trains.

In the author's opinion there are many cases where it will be found that the introduction of flying junctions and the consequent simplification of working will enable electric traction to give a satisfactory and paying increase in facilities, where at the present time with flat junctions

the expenditure of capital for electrification would not give a reasonable return.

As the capital cost of electrification (as regards cables, sub-stations, and the contact conductors at any rate) does not vary proportionally to the train frequency, and is broadly speaking of the same order for train frequencies of say 25 or 30 trains per hour, it follows that it is worth while to spend considerable sums of money on any improvements that will enable the train service to be increased, and consequently to enhance the return from a given expenditure on electrical equipment. More especially is this the case where by some increase in the frequency a decrease in the size and weight of the train can be secured, as an increase in the weight of the train is usually of more importance as affecting capital cost than an increase in frequency of lighter trains.

Frequency of Service and Size of Train Unit.

It is axiomatic that a service of electric trains should be as frequent as possible and that the train should be as short (and therefore light) as possible consistent with giving adequate seating accommodation. Assuming of course the same acceleration and retardation in all cases (the retardation of longer trains is usually slightly lower than that of short ones owing to time lag in brake operation, unless electric operation of the air brake be made use of), the shorter the train the shorter the block section can be made; but although this will give great frequency of trains it does not give the greatest seating capacity per hour. For any given schedule speed there is a definite point where an increase in frequency will actually decrease the seating capacity per hour, owing to the increased frequency necessitating shorter block sections and therefore shorter trains in order to give adequate cover between.

With regard to the maximum possible capacity of suburban lines, a number of very interesting German papers have recently been published in which investigations are made into the limits of the carrying capacity of such lines. The following may be referred to as the more important of a large number :—

Pfeil. *Elektrische Kraftbetriebe und Bahnen.* vol. 5, p. 601, 1907.

Brecht. *Elektrische Kraftbetriebe und Bahnen.* vol. 6, p. 101, 1908.

Brecht. *Elektrische Kraftbetriebe und Bahnen.* vol. 11, p. 220, 1913.

Brecht. *Annalen für Gewerbe und Bauwesen.* vol. 65, pp. 93 and 111, 1909.

Bethge. *Elektrische Kraftbetriebe und Bahnen.* vol. 11, p. 217, 1913.

Brugsch and Briske. *Elektrische Kraftbetriebe und Bahnen.* vol. 11, p. 553, 1913.

On the through sections, *i.e.* not at junctions or termini, the frequency of trains is governed by the time required for one train to brake, stop at a station, and accelerate clear of the station so as to free the signal, allowing the next train to follow.

Brecht has studied the relation between train length and frequency in respect to carrying capacity, and shows that the longer the train the greater is the capacity per hour, because although longer trains require more time to clear sections and can therefore not be operated at such frequent intervals, the time required for one train to follow another does not increase in proportion to the length.

Bethge gives a series of curves showing the influence of train length on frequency, and also the influence of varying acceleration in combination with varying train lengths.

Brugsch and Briske show the influence of the speed of the train at the moment of braking on the distance and time required for bringing the train to a stop, and they give the following figures :—

Speed in km. per hr. at moment of braking	60	50	40	30	20	10
Distance required for braking, metres	174	121	77	43	19	5
Time required from passing train-stop of station home signal to bringing train to rest at platform, seconds ...	41	37	35	34	38	61

Assumed : Length of train, 150 metres ;
Deceleration, 0·8 metre per sec. per sec.

This article brings out the influence of the speed of the train at the moment of applying the brakes on the time required for running into a station, and shows that a speed of 30 km. per hour is the most favourable under the conditions assumed. The article proceeds to discuss the possibility of automatically limiting the speed at the moment of applying the brakes, which the author believes was first suggested by Bion J. Arnold for the New York Subway, and shows that by so doing and by the greatest possible refinements of signalling it is theoretically possible to obtain the following results :—

Train length in metres	60	90	120	150
Time interval between trains in seconds	49	55	60	65
Number of trains per hour in each direction, assuming a station stop of 20 seconds	73	65	60	55

Assuming a figure of 5 seats per metre run of train, this gives the following seating capacity per train and per hour :—

Seating capacity per train	300	450	600	750
Seating capacity per hour	21,900	29,250	36,000	41,250

These figures show that the hourly seating capacity of the larger train is greater than that of the smaller ones at the slightly increased frequency which shortening renders possible.

The hourly seating capacity figures given above are apparently the maxima theoretically possible, and are not likely to be attained in practice except perhaps on a new line built specially as a ring or otherwise so as to have no terminals or junctions. They must not be taken as possible figures on existing lines.

On existing lines with flat junctions and terminal stations, with in many cases curves restricting the speed possible, and with heavy gradients and other disabilities, it is not possible to attain such short headway.

With a length of train of about 150 metres the maximum number of trains possible on a line excluding flat junctions

and dead-end termini may safely be assumed as about 40 per hour, and this figure has been given as the possible attainment on the Berlin Stadtbahn in the 1913 paper by Brecht already mentioned, in which an investigation is given into the carrying capacity of terminal stations in relation to the capacity of the free stretches of line. He shows that for a terminus such as is shown in Fig. 1, consisting of two platform roads used alternately, the number of electric trains which it is possible to run at this terminus under working conditions is 33 per hour, compared with the 40 possible on the intermediate sections. The actual numbers will vary in different cases depending on grades, curves, etc., but broadly speaking the proportionate reduction of train numbers is not widely affected. The reduction shown above, viz. from 40 to 33, is the measure of the disability of the terminus. This ratio may be conveniently called the "terminal factor," and in this case is 33/40 or 0·825.

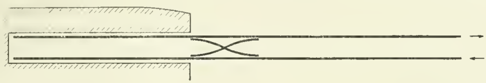


FIG. 1.

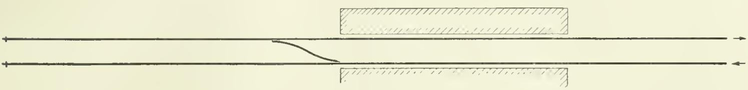


FIG. 2.

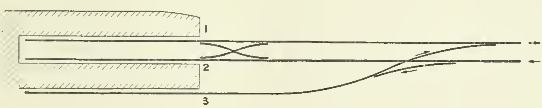


FIG. 3.

The same article compares the relative results with steam working and gives the following figures relating to the Stadtbahn. The possible number of steam trains on the basis of 140-metre trains and an acceleration of 0·22 metre per sec. per sec. on the through sections is given as 32, while the number which can be worked into a terminus such as Fig. 1, is given as 21. The "terminal factor" in this case is 21/32, *i.e.* 0·656.

Comparing the numbers on the through sections, viz. 40 electric against 32 steam, the reduction by using steam is 8 in 40, or 1 in 5; but in the terminal working the reduction is from 33 to 21, *i.e.* 12 in 33, or 1 in 2·75, thus showing the great superiority of electric working over steam for terminal business. This comes about through the requirements of the locomotives. Not only has a locomotive to be attached to the train which has come in, to take it out, but the incoming locomotive has to be detached; and when the train has left, the points for the engine dock have to be operated and this locomotive put in the dock before another train can be accepted.

If the terminal arrangement shown in Fig. 2 can be adopted, where the crossing takes place not at the entrance to the platforms but beyond them, theoretically the "terminal factor" for electric multiple-unit trains can be made unity, *i.e.* no limitation of frequency exists; but it requires one more train to perform the schedule, and the shunting increases the number of non-remunerative train-miles.

For an urban line carrying passengers only, the time during which the train is at rest at the platform in Fig. 1 (*i.e.* not more than the time interval between trains) is sufficient for station purposes, which only amount to unloading and loading passengers and the change of ends by the motorman; but with a trunk-line suburban service there is the requirement of dealing with milk, parcels, mails, etc., and the lay-over given is not always sufficient.

Apart from this the time required for emptying a platform of people arriving by a train governs to some extent the lay-over necessary if the same train is to operate as a passenger train in the reverse direction. In modern rapid-transit projects separate entrance and exit platforms are sometimes provided, but in dealing with existing termini where the exits of the platforms must be in the majority of cases at the ends of the platforms and therefore limited to not more than the platform width, and dealing with two trains running simultaneously into the two sides of a platform, each train discharging anything up to 1,000 people, it will be found to take 3 or 4 minutes before all these passengers are clear of the barriers.

With a distributed service running through the city where a number of stations are available to serve the business area, the same problem does not arise.

With three platforms in use, as shown in Fig. 3, double the lay-over time is obtained, but this involves one extra train in traffic. In this case the conflicting trains are less frequent, but in the worst case of confliction as between a train leaving platform 3 and one entering platform 1 or 2, the time required to clear is greater, so that it will be usually found that the "terminal factor" for such a lay-out, with the usual allowable curves and platform widths, will be of the same order as that for Fig. 1.

Maximum Capacity of a Line with Flat Junctions and Terminal Difficulties.

Bearing in mind what has been said above, the author is of opinion that with trains of 450 ft. length, 30 per hour in each direction on a double line is about the maximum possible over lines where flat junctions are introduced, and where all the trains at the busy end of the system have to be dealt with in a terminus where it is not possible to extend the platform lines as shown in Fig. 2 beyond the platforms and thus do away with the "terminal factor." In the majority of our big stations this is practically impossible.

Under steam conditions and with the same junction and terminal factors limiting the capacity of the line, it is not economically possible to run on a double road more than 16 trains per hour each way. The size of these trains is, however, in many cases very large, and the number of seats in some cases exceeds 1,000 per train. In the case of Liverpool-street Station (which handles probably the biggest steam suburban passenger business in the world), in one hour, on one pair of roads, 15 trains, having a total seating capacity *for one direction* of over 13,000 seats, are worked in each direction into and out of the terminus.

In considering the replacement by electric trains of a steam service giving a seating rate of 13,000 per hour by 15 trains (an average seating of say 870 per train), it is evident that the size of the train must in any case be considerable.

The maximum frequency of electric trains at the present time is about 42 per hour on the District Railway, with 50 mentioned as a possible development when the Earl's Court flying junctions are fully in use. Assuming 50 per hour, the seating capacity of each train must be 260 in order to obtain a total of 13,000 per hour. The seating capacity of a District or Metropolitan train of usual size (6 cars) is approximately 300 seats, so that on one pair of roads and in each direction 50 ordinary Metropolitan or District trains per hour will only give 15,000 seats per hour, as against 13,000 now provided by steam trains on the Great Eastern Railway and on other lines handling heavy suburban traffic. Thus, although 50 such trains per hour (could they be operated) would give an increased frequency of service to the various branches of the suburban system, only a small increase in the seating capacity would accrue, and as all the steam trains are well filled (the maximum number of people per hour on one line being about 13,000, or almost the same as the number of seats) the seating capacity must be increased in order to provide for the extra business which may be expected to be obtainable.

Over the roads and junctions now existing on any general trunk-line system 50 such trains could not be operated per hour, so that for the solution of problems of this nature a much greater seating capacity per train must be provided at "rush hours" than is usual for electric trains, and hence the capital cost of electrification is considerably increased, as an increase of the weight of the train has a greater effect on the capital cost than an increase of frequency of shorter trains.

Assuming that 30 trains per hour can be run on one line (which in the author's experience is about as high as can be dealt with continuously under the circumstances beforementioned), the seating capacity per train must be about 435 in order to equal the existing facilities for passenger travel on the steam line quoted above. To give an increase of 33⅓ per cent in the seating capacity—a very reasonable requirement—a train having in round figures 580 seatsн must be provided. This means a train, allowing for luggage compartments and motormen's cabs, at least 325 ft. long, weighing, without electrical equipment or passengers, some 160 tons, giving about 3·6 seats per ton weight, or 1·8 seats per foot-length of train. The seating capacity of the ordinary side-door compartment cars is higher than that of the end-door type. Various published figures for seating capacity of different trains are available (e.g. *Annalen für Gewerbe und Bauwesen*, vol. 62, p. 227, 1908), and one seat per foot-run of train may be taken as almost exactly the figure for end-door saloon cars such as are used on urban railways generally. The specially wide cross-seat corridor car of the Lancashire & Yorkshire Railway has a seating capacity of 1·62 seats per foot-run.

The side-door compartment cars can be filled and emptied more quickly than end-door cars, and to maintain a frequent service with a short station stop the time of loading and unloading is of very great importance.

The length of time taken by the station stop is one of the most important, if not the most important, of the many factors governing the maximum train frequency. If the station stop be excessive, say more than 30 seconds, the resulting reduction in frequency may be as much as, or more than, that due to a junction, in fact there must be for any given set of general conditions a limiting length of time of station stop, any increase of which nullifies the advantages of the improvements in junctions, etc. The time required for the station stop is affected by many apparently minor considerations. The use of lifts to transport passengers to the trains causes longer station stops than do escalators, as the latter distribute a more regular flow of people. The use of the last possible means to reduce the station stop is justified.

Such devices as train describers, which indicate to passengers exactly which is their train, help in avoiding unnecessary waste of time.

One point in the use of side-door compartment cars which does not appear to have been referred to, so far as the author recollects, is the question of shutting carriage doors of long trains. With the high acceleration of electric working this is no easy matter, a larger staff must therefore be provided to deal with the door shutting, or else longer station stops will have to be allowed.

There are compartment cars with side doors in use for electric trains on the Metropolitan Railway, and on the London, Brighton & South Coast Railway, although the trains are so short that the door-shutting difficulties are not serious. The author has noticed that when the train runs from platforms on the left-hand side of the direction of travel, owing to the high acceleration the doors tend to shut themselves as the train starts, or only require a small push; but where the doors are open in the reverse direction (as must happen with some platforms at terminal stations, or at an island platform on a double line) the difficulty is likely to be very considerable.

The train unit must be so chosen as to be capable of being split up into smaller units for times of lighter traffic, keeping a due proportion of luggage space and accommo-

dation for various classes in each section unit. The facility with which electric multiple-unit trains can be broken up into shorter units and the absence of any engine shunting in such operations is of course well known, but an incidental drawback to this advantage is the necessity of finding more siding accommodation at various points where the trains may require to be split up. This is not an easy or cheap matter in the majority of cases.

In the case of railway systems where some of the suburban stations are termini, the platform roads at such stations can be utilized for the storage of trains at night.

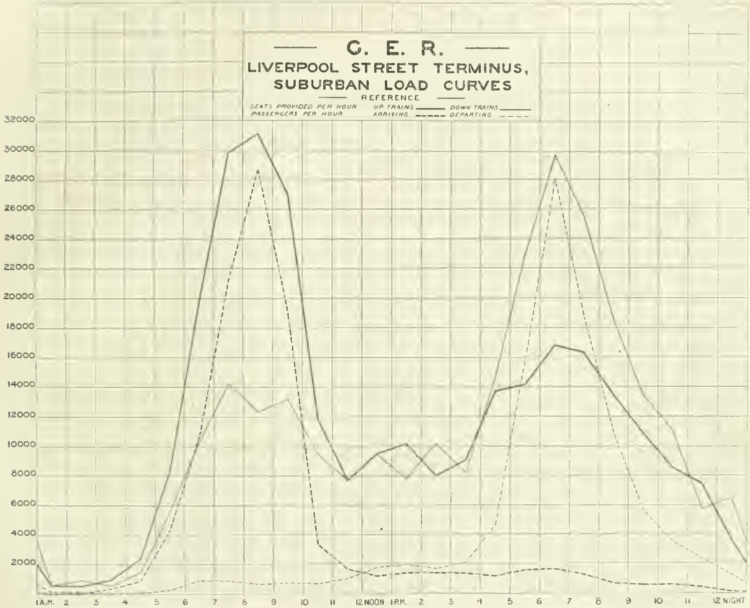


Fig. 4.

Load Factor of London Suburban Traffic.

Fig. 4 shows the week-day suburban passenger traffic of Liverpool-street Station and gives not only the number of passengers per hour but also the seats per hour. It shows incidentally that over a period of one hour a greater number of seats is provided than is required, but it must not be taken from this that there is not some overcrowding of individual trains. Whatever system of traction be employed there are almost certain to be some trains which are overcrowded. This is especially the case with the last of a series of trains which arrive at the terminus before a given time in the morning and by which cheap fares are available. The last of these trains is certain to be overcrowded even if a frequent service be given immediately before.

The curve shows the bad load factor of London suburban traffic. It is the average daily business and does not in fact deal with what is the worst period, Saturday between 1 p.m. and 2.30 p.m. For example, Liverpool-street Station deals with in round figures 200,000 passengers per day on average week-days, approximately 100,000 arrivals and 100,000 departures, *i.e.* an average of say 4,150 per hour in one direction; but in the busiest hour, 1 p.m. to 2 p.m. on Saturdays, the number of outward suburban passengers is approximately 36,000, dealt with of course not on one line of rails but to some extent on three. The inward traffic at that time is small and the maximum number of passengers in one hour "up" and "down," main-line and suburban, is about 38,000. The "daily passenger load factor" of Liverpool-street Station is therefore :—

$$\frac{200000 \times 100}{38000 \times 24} = 22 \text{ per cent approximately.}$$

The load factors of other similar termini are of the same order, and in some cases lower.

The importance of load factor in any business is obvious to members of this Institution, a great part of whose difficulties in all branches of the supply of energy for power and lighting is due to poor load factor. Members may rightly claim that the scientific investigation of the subject and the recognition of its vital importance on the economics of any project are to the credit of electrical engineers.

The question of load factor in transportation is one therefore of peculiar interest to this Institution. It may here be mentioned, as showing the wisdom of those responsible for running the motor omnibuses, that the "rush hour" service is not much greater than the service during normal hours. This is excellently brought out in Plate 3 of the Report of the London Traffic Branch of the Board of Trade, 1912, in which a diagram is given comparing the normal and "rush hour" services on the Tubes and the motor omnibuses. The proportion between the number of seats operated by motor omnibuses at times of average traffic and those operated at "rush hours" is roughly 0·9, *i.e.* the number of seats run at average times is 90 per cent of the number run at peak time. Unfortunately the 1913 Report does not give a corresponding diagram, and the number of motor omnibuses has very largely increased since 1912. The author thinks, however, that the relation between the average and peak seating capacity operated remains much the same. Mere observation shows that the ratio is far higher than in the case of railways. The omnibuses evidently do not lay themselves out to cater for peak-load business.

Suburban passengers fall into two great classes :—

(1) Season-ticket holders;
(2) Ordinary passengers;

and the relationship between the numbers of each is an indication of the character of the traffic. Broadly speaking the season-ticket traffic is peak-load traffic, whilst the "non-rush hour" traffic is very largely ordinary ticket passengers. It is this latter traffic which has suffered most severely by road competition, for two reasons :—

1. The poor and infrequent steam service given on some lines at "non-rush hours."
2. The lack of through-running to shopping and amusement centres.

The latter point is of great importance to this class of passenger, but the season-ticket traffic does not feel it to the same degree because it is almost entirely business traffic, and this to a large extent chooses its residential suburb with regard to the convenience of the terminal station to its business centre. It is also of importance to arrive at business at a definite time, and a railway service is more reliable in this respect than road transport.

The "non-rush hour" business is mainly quite different in character, being more of the nature of shopping, theatre, and social traffic, which requires to be carried to various portions of the metropolis, and is not content to be landed at a terminus and have then to take an omnibus or tube when an omnibus can usually be found giving a through-service from the suburb to any portion of London. Further, this traffic is not tied rigidly, like business traffic, to arrival at a definite hour. It is in this section of the suburban business where trunk railways have lost ground, while the season-ticket business tends steadily to increase.

Some interesting figures are given in the 1913 Report of the London Traffic Branch of the Board of Trade as to the growth of ordinary ticket receipts and season-ticket receipts on the larger railways entering London. These figures show that ordinary ticket receipts have increased from £10,824,897 in 1906 to £11,029,573 in 1912, an increase of 1·9 per cent. Season-ticket figures for the same period have increased from £1,694,198 to £1,865,832, an increase of practically 10 per cent. These figures include all travel on the railways dealt with, and are therefore only a rough guide to the situation.

It is well known, however, and has been referred to by several railway chairmen at company meetings, that the season-ticket receipts have grown while the ordinary ticket receipts from London suburban traffic have actually decreased in many cases.

The return on the investment necessary for electrification must be looked for in the increase of the "non-rush hour" traffic far more than in any further development of the peak, involving greater capital expenditure and worse operating conditions. If the railway traffic which is illustrated in Fig. 4 be electrified, its power demand will be represented by a similar curve and load factor (really rather worse, as car movements will increase the peaks).

Fig. 5 is a curve for Liverpool-street Station showing combined "up" and "down" passenger movements for suburban services, as well as the combined "up" and "down" seats run both in booked passenger trains and in car trains. It emphasizes the very large unremunerative peak of empty car movements which must of necessity be run at "rush hours," and shows how this dormitory business of London employs for two limited periods per day a seating capacity otherwise largely idle, and even during these peaks there is a large amount of light mileage, as the traffic is almost all in one direction and the trains therefore run empty in the other direction.

Let us consider how the electrical engineer would handle a similar load curve in the case of power supply. There is no question that if money is no object it is well to have the most efficient and modern plant for the whole load, but there are many supply businesses where the peak is dealt with by older plant, or older stations, not as efficient or modern as is to be desired for the continuously running plant.

The two methods available for dealing with an electric power-supply load of this nature are :—

1. To increase the load factor by obtaining cooking, heating, and other non-peak load business.
2. To supply the peak by existing plant of comparatively high running cost rather than to install new plant purely to deal with peaks.

The economical way to deal with a traffic problem of the nature shown in the curve appears to depend on precisely similar considerations.

1. The Improvement of Load Factor.

The improvement of the load factor of suburban services depends, in the author's opinion, largely in the

possibility of developing through-running; and also on the provision of a frequent and quick service during "non-rush hours," which can be given economically only by electricity.

An interesting experiment in what electrical engineers would call "restricted-hour service" is the institution by the Metropolitan Railway of ladies' season tickets available only after 10.30 a.m. when the morning peak is over.

No doubt something may be done in this direction to improve the passenger load factor in the same way as electric-supply load factors have been increased by encouraging cooking, heating, and power demands, although the nature of the locality served by the railway may affect the possibilities in this direction.

The author would like to point out that in considering the increased traffic obtainable by electrification, two factors must be considered :—

1. The frequency and convenience of the existing steam "non-rush hour" service.
2. The nature of the business, particularly whether urban or terminal.

It must not be assumed that the excellent results as regards increased traffic that have been shown on some electrified lines can be reproduced in all cases, as in some of these cases the steam all-day service previously given was very irregular, infrequent, and slow. Where, however, efficient all-day steam facilities are given, the same proportionate increase by electrification cannot be looked for. This is balanced, however, by the fact that in those cases (and they are more numerous than some people think) where all day a good steam service is provided, it is only at a very high cost of working, and on the whole therefore electrification is likely to show better results, but in this case partly by an increase in the business and partly by a decrease in the operating cost, rather than by an increase of business only.

Where the business is urban in character, or where through-running on to an urban system can be achieved, the increase in all-day business can undoubtedly be made very great by adequate facilities; but where the service is terminal the increase of business obtainable even by an increase of frequency is unlikely to be of quite the same

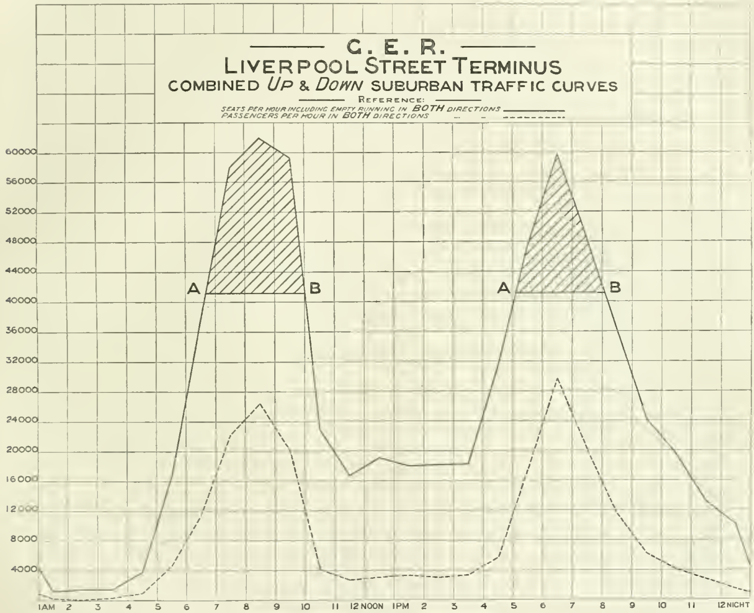


FIG. 5.

magnitude. The nature of the district served has also to be very carefully considered in estimating the possibilities of increased traffic. Obviously in a case such as the Liverpool–Southport line, the possibilities of all-day traffic between a large business town and an important seaside residential and pleasure resort with a very eligible residential district throughout the entire route, are enormous and depend simply on an adequate service. The conditions for an electric line are in such cases at their best, and such districts can only be properly served electrically; but the results from a radial line serving a number of purely residential suburbs cannot be expected to be of quite the same order except in certain cases, as, for example, the traffic between London and Crystal Palace, where again there is important all-day traffic to be secured as well as an exceptionally rich residential neighbourhood to be served. In this respect, again, the situation is similar to that of electric power supply where the nature of the district supplied may considerably affect the possible development of off-peak supply.

2. Handling the Peak Business with Cheap Plant.

The broad distinction in operating featu es between steam and electric traction is that steam is expensive in running costs but cheap in capital charges, while electricity has the reverse characteristics. On heavy peak traffic the electric equipment required cannot save sufficient in operating expenses during the comparatively short user possible to meet the increased capital charges, in exactly the same way as many power stations cannot show a return on the investment required to provide modern plant of high operating efficiency for a peak which does not last long enough to enable these operating savings to offset the increased capital charges.

As steam can deal economically with rushes and electricity economically with steady high-load-factor traffic, the logical solution of a traffic problem such as is presented by the curve in Fig. 5 would appear to be to perform the lower solid part of the curve electrically leaving the peaks to be dealt with by steam.

This solution may at first sight appear impracticable and probably would be so in many cases, but the author is of the opinion that logically it seems to be sound and at any rate is certainly worth investigation in a number of cases. The difficulties are mainly :—

1. Terminal working of locomotives.
2. Combined working of steam "rush hour" trains superimposed on a regular electric service.

It may be stated at once that such a solution could only be considered in the case of a line operating a considerable steam business apart from its suburban traffic. In this case the cost of providing for repairs to the steam plant which might be used for suburban peak business would be small, and the organization of the working might be arranged to fit in with other steam services.

It might not be desirable to operate such a system for a purely suburban railway having no general trunk-line traffic. On a line, say 10 miles long, having only two tracks it would appear to be impossible to work a service like this, but on a radiating system running into a terminus with many platforms the author is of opinion that it appears worthy of study, more especially in cases where the peak load of main-line business does not normally coincide with that of suburban business, and many of the steam "rush hour" trains might be accommodated on the relief or main lines as they are at present.

It must not be forgotten that "rush hour" suburban business is largely "non-stop"; for example, an "up" morning "rush hour" train often picks up its full load at two or three stations—in some cases only at one station —and then runs through to the terminus giving precisely the best conditions for steam working. In services such as this the superior acceleration of electric trains has not the opportunity of showing much advantage, and the schedule speed of steam trains on such runs not hampered by frequent stops is as good as can be made by electric trains, especially by such electrical equipments as are best fitted by gear-ratio considerations for performing frequent-stop services.

Although the difficulties of working the locomotives would be considerable, they would be no more than they are at present. The electric service being of a regular nature could be quite well worked at the terminus into a very small number of platforms, and the extra carrying capacity given by the electric trains might enable the "rush hour" steam trains to be slightly reduced in length and weight and thus to have better acceleration, or alternatively to be reduced in number. The terminal facilities for a mixed traffic of this nature would of course be greatly improved if the electric trains could be arranged to run through on to urban distributing systems and not to stop at the steam terminus. The handling of the two classes of trains through complicated junctions would be difficult if there were very frequent stoppages (due to signal checks) of the steam trains, as owing to their slow acceleration the latter require a long time to pick up speed again.

The provision of "run round" lines at some points to enable a steam non-stop train to pass an electric train at a station would enormously improve the flexibility of the service and might do a good deal to enable such a combined service to be operated. It would be equally valuable in all-electric services where any of the trains are run non-stop. This solution would seem to be particularly attractive in cases where physical connections with distributing urban lines already exist capable of taking a portion of the traffic large enough to deal with the all-day business.

A very interesting case in point (all steam worked, however, at present) is provided by the London traffic of the Great Northern Railway, which line has a very heavy suburban business. There is a physical connection from the Great Northern Railway just north of King's Cross terminus to the Metropolitan widened lines, which are used by the Great Northern and Midland Railways jointly to Moorgate-street. A study of the Great Northern suburban services will reveal the fact that a more or less steady through-connection between suburban points and Moorgate-street is given, but that the "rush hour" traffic is largely dealt with by trains terminating at King's Cross. The 1913 Report of the London Traffic Branch of the Board of Trade gives the following number of suburban trains arriving in London up to 10.30 a.m.: King's Cross 44, and Moorgate-street (G.N.) 33. The difference between

the two curves of traffic is well illustrated in Fig. 6, Curves 3 and 4.

Probably even under electrification conditions the "rush hour" traffic would be too large to be entirely dealt with to Moorgate-street, but a very attractive, yet cheap, solution in the case of the Great Northern Railway would appear to be to electrify a steady regular service of reasonably small trains to Moorgate-street, leaving the steam trains to deal with the peak loads as at present. It may be urged that the tendency would be to overcrowd the electric trains and leave the steam trains less well filled; but the author does not think so, because obviously the electric trains would be used for the stopping traffic (for which they are so much more suitable than steam trains can possibly be), leaving the "rush hour" terminal steam trains to do a service which would give perhaps not such facilities in intermediate service, but still as good a schedule on the longer runs as could be provided electrically.

As showing this discrimination between "terminal" and "through" trains even under steam working, the figures for the Great Northern Railway are interesting. In the Report of the London Traffic Branch of the Board of Trade, 1913, Appendix B 15, the following information is given:

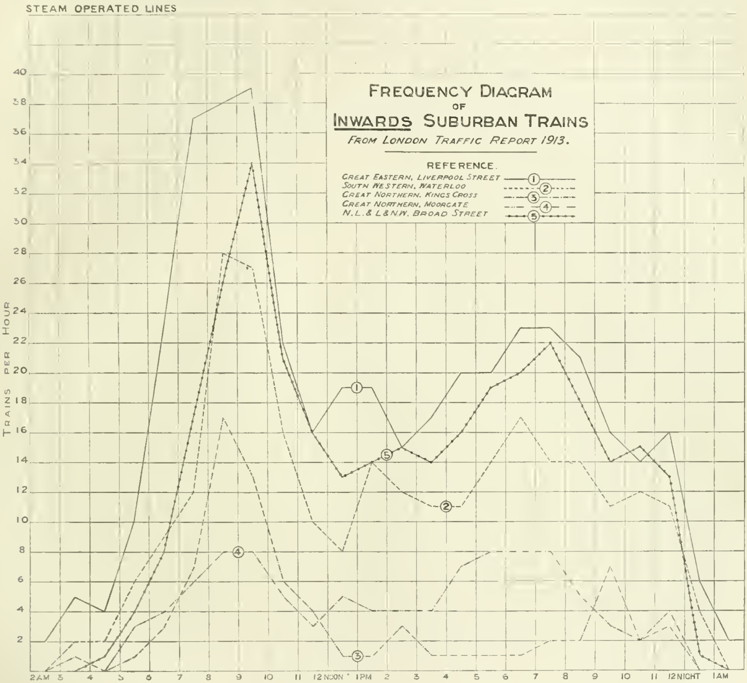


FIG. 6.

	No. of inward suburban trains between 8 a.m. and 9 a.m.	Average rate of speed
(G.N.R.) King's Cross ...	17	22·9 m.p.h.
(G.N.R.) Moorgate-street ...	8	17·2 ,,

These figures confirm the impression that the terminal business at King's Cross is composed of the more or less non-stop trains, while the Moorgate-street connection gives a more distributed service.

A table is given in Appendix B 18 to the 1913 Report of the London Traffic Branch of the Board of Trade showing the number of inward suburban trains at various points during the 24 hours. The author has had some of the more interesting of these figures put in diagrammatic form (see Figs. 6, 7, and 8), and the curves show very clearly case; and in the other cases it may be assumed that the curves would be similarly affected. No information is given in the figures mentioned as to the size of train, but merely of train frequency, nor are any recent figures available as to the passenger load factor, *i.e.* the numbers travelling at various times.

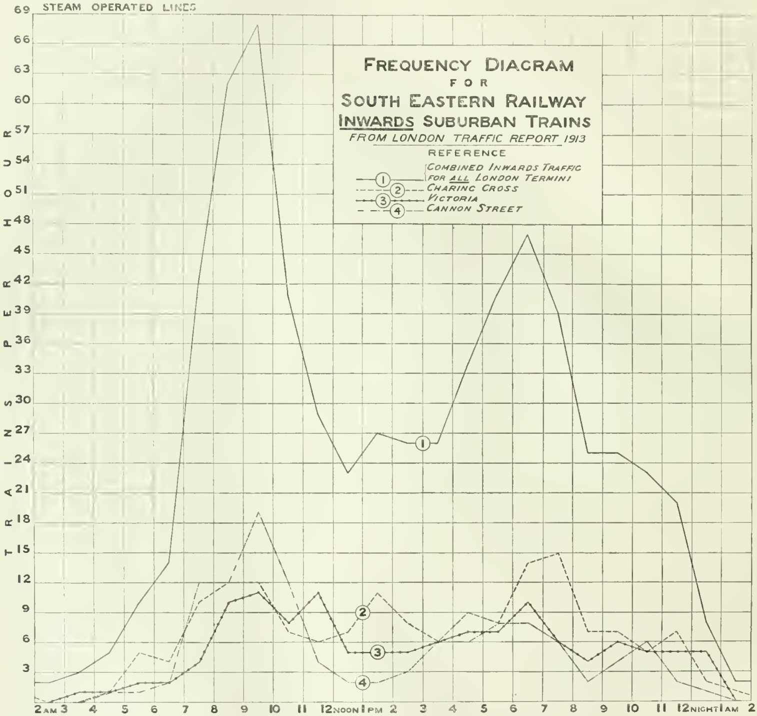


FIG. 7.

the difference in train frequency as between "rush hours" and "non-rush hours" in the case of heavy radial suburban business, and the much greater regularity of train frequency in the case of urban lines distributing their traffic over the central area.

The table unfortunately deals only with inward suburban trains, and this explains the relatively small evening peaks shown. In Figs. 4 and 5 the author gives the actual curves for both "up" and "down" traffic in one

A large number of diagrams of passenger movements at various termini were given in 1905 by the Advisory Board of Engineers to the Royal Commission on London Traffic. The developments and alterations in London traffic conditions since 1905 are such as to render these diagrams of little use. In the case of stations in the City of London some figures for a portion of the day are available in the report on the "City of London Day Census," 1911.

The following figures may be given :—

	Minimum Number of Passengers in One Hour	Maximum Number of Passengers in One Hour	Min. / Max.
			Per cent
(G.E.) Liverpool-street ...	1,509	23,316	6·5
(S.E. & C.) Cannon-street	485	8,431	5·75
(Met.) Bishopsgate-street (now called Liverpool-street)	734	3,007	24·5
(Met. Dist.) Mansion House	500	3,020	16·6
(Central London) (Bank)*	800	2,600	30·6

* Extension to Liverpool-street not then open.

Unfortunately this census only lasts from 7 a.m. to 7 p.m., and neglects therefore a very considerable portion of suburban traffic, and even these figures are somewhat out of date as considerable alterations (particularly the growth of motor omnibus traffic) have occurred since then. So far as they go, however, they show the great distinction between traffic on urban lines like the Metropolitan, Metropolitan District, and Central London Railway, and that on radial lines like the Great Eastern and South-Eastern and Chatham Railways.

In the case of steam lines it must be remembered that these figures include all passengers, whether suburban or long distance.

The figures for the departure traffic would show an almost exactly similar comparison.

In the case of urban lines there is a considerable flow in both directions all day, and the radial traffic is much more of a peak nature, all "up" in the morning and "down" at night."

The curves shown bring out the fundamental difference between "urban" and "radial suburban" traffic, and show the very great importance in the latter case of the "rush hour" business. An investigation of the actual figures will be of interest. Referring to the curve shown in Fig. 5 the lines A B, A B, are drawn at an arbitrarily chosen point

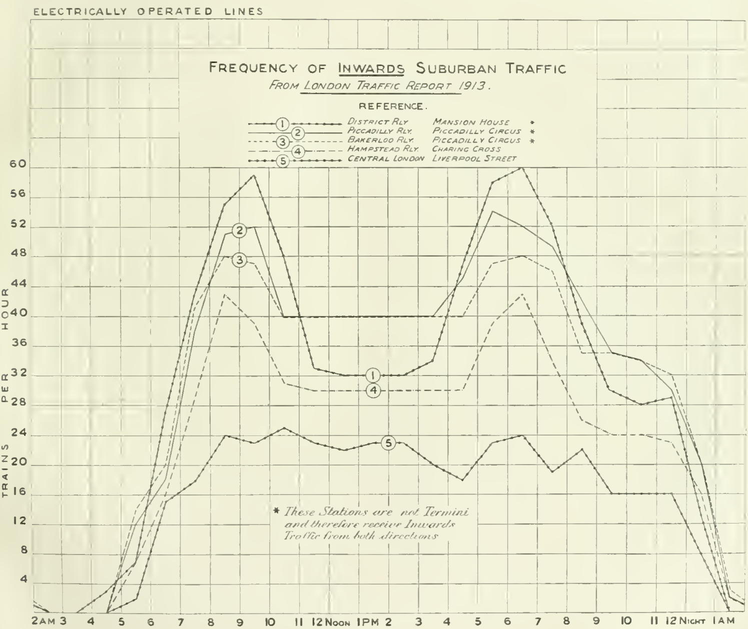


FIG. 8.

two-thirds of the maximum height which represents the number of seats per hour. The two areas of the curve above A B, A B, represent about 87,000 seats, and the part below these lines about 615,000. The total is 702,000 seats, being the number of seats moved in both directions per day. The areas represent of course the number of seats per hour multiplied by the time, *i.e.* the total number of seats moved. The areas of the portions of the curve above the line represent 87,000/702,000, or 12·4 per cent of the total number of seats moved per day, while the lower portion represents 615,000/702,000, or 87·6 per cent of the whole; or, to put it another way, the two peaks are satisfied by running 87,000 seats above the 615,000 of the lower portion, or an increase of 14 per cent; but the maximum demand is increased from 42,000 seats per hour to 63,000 seats per hour, or by 50 per cent.

The maximum peak load above the line A B represents 21,000 seats per hour. Assuming an average train capacity of 780 seats per train, *i.e.* taking about the maximum train reasonably worked, viz. about 440 ft. long, 27 train-trips will be necessary per hour to deal with this business. Assuming a schedule speed of 22 miles per hour, a lay-over time at each end of the journey of 4 minutes, and an average distance of run of 10 miles, the time required for one train-trip is 31 minutes. The number of trains required in service at one time to carry out 27 trips per hour is therefore 14.

The area of the two peaks above the lines A B represents 87,000 seats. At an average train capacity of 780 passengers this represents 112 train-trips per day, or 1,120 train-miles per day, or, assuming that this peak occurs on 300 days per year, 336,000 train-miles per annum. With 14 trains required for performing this service, this gives 24,000 train-miles per train per annum.

If the trains at peak times could all be run non-stop through a number of stations the schedule speed might be more than 22 miles per hour. Assume it to be 28 miles per hour, which is not likely to be exceeded as a fair average figure for all the trains at peak time, the run of 10 miles will require 21·5 minutes, and with 4 minutes' lay-over at each end the trip time will be 25·5 minutes; therefore if 27 trips per hour were required, 12 trains would perform the service. The train mileage per train per annum in this case would be 336,000/12, *i.e.* 28,000.

The height of the curve at the lines A B represents 42,000 seats per hour. On the same assumptions as before for average train capacity, schedule speed, and length of run, viz. 780 seats, 22 miles per hour, and 10 miles respectively, 53·5 train-trips per hour will be necessary, requiring 28 trains to deal with the traffic. The area under the lines A B represents 615,000 seats or 800 train-trips per day, or 8,000 train-miles per day. As a large proportion of this business will be handled on Sundays as well as on business days, the mean number of days per year will be about 340. The number of train-miles per year will be 2,720,000 or 97,000 train-miles per train per annum.

These figures ignore questions of spare stock under repair, and undoubtedly more spare stock proportionately would be required for the latter portion of the service than for the former. Allowing for this consideration, however, the figures do show the very restricted user of rolling stock possible on such a traffic as that shown in these peaks compared with the user in general.

An 8-car bogie train of a length of about 450 ft. will require, for a severe suburban schedule, three of the cars to be equipped as motor cars, each with an equipment of four motors each of over 200-h.p. output. The capital cost of such equipment, including trailer-car apparatus, will be at present prices about £10,000.

In the case of the 14 trains working the peak above A B making only 24,000 train-miles per annum (if restricted solely to suburban work as they might have to be, as already pointed out), the interest and depreciation (at 10 per cent) on electrical equipment alone will amount to 10d. per train-mile. If the train mileage can be increased to 28,000 the figure will be 8·6d. per train-mile.

As this peak-load traffic is to a large extent less severe in service characteristics than the average traffic (owing to some of the business consisting of non-stop running) it might be possible to handle it with trains equipped with less powerful and less costly electrical apparatus, and in some cases it might pay to do so, but that introduces the very undesirable feature that in addition to the trouble of the suburban stock being incapable of utilization for holiday business on non-suburban lines (unless the holiday lines are also electrified), the suburban stock itself would be of two kinds, and the lightly equipped suburban trains would be unable to perform heavy suburban schedules or to act as spare stock for such a service.

From an operating point of view this method of reducing the capital charges is not feasible, as it would be necessary to have all suburban trains of standard equipment suitable for the severest service conditions, and suitable for operating either "non-stop" or "all station" traffic as the circumstances might require. One round trip ("up" and "down") may demand both characteristics. Assuming that power be bought from outside sources, the price charged would unquestionably be decided by any commercial supply authority on the basis of the load factor of the demand. As the evening peak of traffic largely coincides with the winter lighting and power peak, the diversity factor cannot have much effect. If the railway should decide to generate its own electrical energy the capital cost of the plant necessary to supply the top $33\frac{1}{3}$ per cent of the load shown in Fig. 5 would be at least 25 per cent more than that of the plant required for the bottom $66\frac{2}{3}$ per cent. In addition, the cost per unit of generating the energy for the peak would be considerably higher than that of generating the bulk. Additional boilers worked up for a limited time, or alternatively the overloading of boilers regularly used, would cause an increase in the cost of coal per unit, extra staff would be required, and the conditions generally would obviously be unfavourable to the most economical operation.

Cost of running "Peak" Service.

A train of 780 seats will weigh, with passengers and electrical equipment, some 320 tons. Such a train operating at a schedule speed of 22 miles per hour with station stops 0·9 mile apart, will result in an average load at the power house of 500 kw. The 28 trains necessary to run the bottom portion of the curve in Fig. 5 will therefore make an average demand of 14,000 kw. The momentary peak load will be say 17,500 kw.

With 12 additional trains running (assuming the lowest number required for the peak), *i.e.* a total of 40 trains, the figures will be :—

Average load at power station	20,000 kw.
Momentary peak at power station, say ...	25,000 „

An increase in the number of trains from 28 to 40 necessitates an increase in the momentary peak of 7,500 kw., or 43 per cent. It may therefore be taken that additional plant of about 8,000 kw. capacity would be required, which would cost say £10 per kilowatt, or £80,000. Interest and depreciation at 10 per cent is £8,000 per annum. The number of train-miles run by these 12 trains during peak times is 336,000. The capital charges on the extra power station plant are therefore 5·7d. per train-mile.

The capital charges on the electrical equipment of the rolling stock have already been stated, on the basis of 28,000 miles per train per annum, as 8·6d. per train-mile. The total capital charges may therefore be stated as 14·3d. per train-mile.

As the service is assumed to be to some extent of a "non-stop" character, 80 watt-hours per ton-mile can be assumed as a reasonable figure (certainly not too high) for such a service. A 320-ton train will therefore require about 25 units of electrical energy per train-mile. Assuming the cost of energy to be 0·3d. per unit (excluding capital charges) the cost of energy per train-mile will amount to 7·5d. Adding the cost of the motormen's wages and the repairs and maintenance of the rolling-stock electrical equipment at say 4·5d. per train-mile, the operating cost per train-mile will be 11·5d. So that including the following :—

1. Rolling stock equipment capital charges ...	8·6d.
2. Power station equipment capital charges ...	5·7d.
3. Operating costs	11·5d.

the total cost per train-mile at peak times equals 25·8d., or approximately 26d. This figure is obtained without including any capital charges for sub-station plant or transmission cables, or for third rail or other contact conductor, or any operating cost for the maintenance of the third rail, etc., and it is therefore unduly low.

The cost of operating by steam such a peak service as that shown would not be more than 15d. per train-mile, so that electrical operation at peak time shows an increase of 11d. per train-mile without charging to it all the items that it should bear. On 336,000 train-miles per year the additional cost in round figures is £15,000 per annum.

These figures are not put forward as estimates of the actual costs to be expected in any given case, but for the purpose of comparing the conditions of steady load traffic as against peak load.

As regards the steady portion of the curve the position is obviously quite different. For example, the charges on rolling-stock equipment, assuming 60,000 train-miles per train per annum, are reduced to 4d. instead of 8·6d. Power station capital charges would be reduced in approximately the same proportion, while the cost (per unit) of generating the energy would be considerably lower than at peak time.

A reduction in the number of cars forming the train does not reduce the cost of steam haulage proportionately to the reduction in weight, while with electric operation the operating cost varies more in proportion to the size of the train, so that if the size of the train be halved and the number of trains be doubled the cost will be of the same order except for motormen's and guards' wages, which are, per train-mile, practically the same whatever the length of train.

By electric operation during "non-rush hours" (so far assumed as performed by trains of the same length as those used at peak times) the cost of operation can be reduced by shortening the trains where possible while retaining the same frequency.

Such comparatively good-load-factor working as results from leaving the peaks to steam can therefore be made at small extra cost much more attractive by electric working, at any rate at an extra cost almost certain to be more than wiped out in any average conditions by the increase of revenue due to the more attractive transport. In this kind of work electric traction can make an unanswerable challenge to steam working from both the operating and the financial points of view; but on "rush hour" traffic of intense character for a short time the figures given show that the electrification of peaks of a traffic load curve such as is shown in the figure can scarcely be a financial success at present fares on the basis of providing a seat for every passenger at "rush hours."

Possibility of reducing Peak by use of End-door Cars.

As to whether the introduction of end-door saloon cars such as are used on the Tubes and similar lines, thereby providing plenty of standing room but a limited number of seats (handling, however, a large number of passengers per unit length and weight of train), would be accepted by passengers on trunk lines as cheerfully as they appear to have been on the Tubes, is a question that the author considers debatable.

The average distance travelled per passenger—at any rate at peak times—is greater in terminal suburban traffic than in urban transport.

It was mentioned by Mr. Bowden in the discussion on Mr. O'Brien's paper* that in the case of the Metropolitan Railway, on which line both side-door compartment cars and also end-door saloon type cars are used, many passengers seem to prefer the former.

Assuming the possibility of operating a mixed suburban service of steam "rush hour" trains superimposed on a regular electric service, the financial aspect of such a proposition in cases of abnormal peak traffic appears to be more favourable than in the case of total electrification.

In the author's opinion the figures given show that this method is worth investigating in such cases as may be found suitable for its use from an operating point of view. It has the merit of still leaving rolling stock available for Sunday and Bank Holiday excursion traffic.

* *Journal I.E.E.*, vol. 52, pp. 458–9, 1914.

Discussion.

Mr. Smith. Mr. Roger T. Smith: It is appropriate that this paper should be the last of the present series of papers on railway electrification, because of the paramount importance of the traffic side of the question. The electrical engineer has, if not the simplest, at least the most straightforward share in the electrification of a railway. Financial considerations are paramount, but traffic considerations come next, and it is right that at the end of such a series of papers as we have had, the great importance of the traffic problems which govern railway working of every sort should be emphasized as it has been in this paper. Mr. Aspinall is the author of more than one trite saying in connection with the electrification of railways, and one of his latest is that in order to be financially successful it is necessary to choose the right locality for electrification. I venture to think that the present paper is written practically on that text, and it is particularly expressed near the top of page 620. I should like to congratulate the author on the excellent analogy that he has made between the peak-load business of electricity supply and the peak-load business of moving seats for railway passengers, and also on the analogy between the load factor for electricity supply and the daily maximum demand load factor for passenger or seat loading. I must, however, issue a warning against importing what is a purely electrical term into railway working. As an electrical term "load factor" always means one of three or four things, and needs another word in front of or behind it in order to express which of those things it does mean. "Passenger load factor" or "weight-of-goods load factor" as a railway term is admissible and would always be understood by railway men, because the term loading, either of goods or passengers, is a commonly accepted railway term. Except, however, as an analogy happily illustrating the point that the author wished to impress upon us—that is, the cost of actually running the peak-load business, which is brought out in Figs. 5, 6, 7, and 8—I feel bound to object to the term "train load factor" or "seat load factor" as applied to the ratio of the average number of seats or the average number of trains per day or per year to the maximum number of seats or trains respectively. The term will undoubtedly be misunderstood by railway men. We ought, however, to have a term to represent those ratios, and tentatively I should like to suggest "utility factor," which although it has been suggested for use in electricity supply, has not yet been generally adopted. The author defines a suburban service, whatever be the length of the journey, as a service with a bi-daily peak, one peak "inwards" traffic, and the other peak "outwards" traffic, with a bi-daily season-ticket traffic which probably predominates over the other traffic. He further defines a "main-line service" as one serving widely scattered communities distinct from each other and without any well-defined bi-daily alternating peak or a large residential traffic. It is very important that we should have clear definitions for these services on a traffic basis rather than on an engineering basis, in order that electrical engineers may tackle their part of the problem; and we want if possible to have definitions covering all kinds of traffic, including goods traffic. In that respect the author's preliminary contributions to these definitions are both important and suggestive. Mr. Smith.

The first five pages of the paper, up to and including the paragraph finishing with flying junctions on page 614, point to the ideal of a separate pair of tracks exclusively used for electric suburban service, confined to that and signalled for that. I am quite aware that the author does not directly advocate it, but he hints at it as an ideal. I would go further and say that it may be essential. Whether it is really necessary or not depends very much on the relative importance of the main-line and suburban traffics. On the Great Eastern Railway, for instance, I believe something like 70 or 80 per cent of the total number of passengers are suburban passengers, and in that instance it may become a case of trying to provide separate tracks for the main-line traffic. In the case of the North-Western Railway, however, where the main-line traffic is of the greater importance, they have thought it worth while to install separate lines for their suburban service as far as Watford; and that very well illustrates, I think, the two extreme cases. In order to decrease the headway the author proposes, on page 613, to fix a speed limit for main-line trains where main-line and suburban trains have to use the same tracks. Whether it is wise to do this or not depends, again, on the relative importance of the main-line traffic and the suburban traffic. The matter, however, is worthy of due consideration, for I think this is the first time it has ever been suggested. The advisability of the author's proposal to work the top of the peaks shown in Fig. 5 by steam, the remainder of the traffic being worked electrically, depends on the accuracy of the comparison that has been made between the cost of steam working and of electric working. In his Presidential Address to the Institution of Mechanical Engineers in 1909,* Mr. Aspinall showed that when electrical working was being introduced on the Liverpool–Southport line, and steam trains had to be sandwiched in between electric trains, the coal consumption of the steam locomotives on a service which to-day is running at a scheduled speed of 25 miles per hour for the stopping trains—I do not know what the speed was at that time—was 100 lb. per mile for stopping trains, and for non-stopping trains 80 lb. per mile. With coal at 12s. 6d. per ton this represents about $6\frac{3}{4}$d. per train-mile for the stopping service. On page 625 the author gives 15d. per train-mile as the cost of running this peak service at a schedule speed of 22 miles per hour, which is probably not much below what it was in the case of the mixed service on the Southport line. I should like to ask whether that is a carefully prepared estimate, or whether the figures, which include a coal cost of probably something like $7\frac{1}{2}$d. per train-mile at present coal prices, were obtained from actual experience. Railway people are ignorant about the relative steam costs of suburban working and main-line working. It is extremely difficult with steam working to separate the two, and I am rather anxious to know how far the above figure is a mere estimate and how far it corresponds with facts: my own belief is that 15d. per

* *Institution of Mechanical Engineers, Proceedings*, 1909, No. 2, p. 452.

train-mile is too low. In making the comparison the author has taken capital charges as 10 per cent. Surely that is too high: 7 per cent is more nearly the figure that should be taken. I also did not quite understand in the comparison why on page 625 the author has included the capital charges on the electrical equipment, but has excluded the capital charges on the locomotive. Surely the locomotive capital charges should be included on the other side. I am quite aware that his figures do not represent an accurate estimate, but only a tentative estimate to show the order of the comparison, but it is very important to railwaymen and others that we should have these figures as nearly correct as we can get them.

The author's proposals for the non-stop suburban service to be run by steam and for the stopping service to be run electrically are actually to be seen in operation to-day in one instance, and soon there will also be another instance in the London suburban railways. The existing steam service on the Great Central Railway between Marylebone and Aylesbury is by Statute not allowed to stop this side of Harrow. That means for $9\frac{1}{4}$ miles it is a non-stop service. The minimum fare, excluding workmen's fares in the morning and evening, is 8d., and the trains go out full with nobody paying less than 8d. This is a most important point indeed for the success of a suburban service. Beyond Harrow these steam trains are stopping trains. This line is paralleled by the Metropolitan Railway, with a stopping service of electric trains up to Harrow. Unfortunately two railways are concerned, but if the two are considered as one it would be an excellent illustration of the principle advocated by the author. The other case, which is somewhat similar, is represented by the work now being carried out by the Great Western Railway for a suburban service that joins the Central London Railway at Shepherd's Bush and goes out to Ealing. This line will be worked electrically, and will carry right into the City all those passengers from up the line who care to change trains at Ealing. The general suburban service of the Great Western line to Paddington is run by steam trains. There will shortly be a third instance; for when the London and North-Western suburban lines are electrified, electric trains will run via the Tubes all the way from the Elephant and Castle to Watford, thus missing Euston altogether and relieving that station of some of its terminal traffic. The suburban traffic between Euston and Watford will be hauled electrically over lines built and used exclusively for this electric service, as mentioned previously.

Mr. O'Brien. Mr. H. E. O'Brien: This paper deals so specifically with London conditions that it is only with considerable diffidence that those concerned with provincial railways may venture to discuss it. The main question dealt with is the working of the traffic peak load. This peak is inseparable from the nature of railway urban business, and it has two aspects—one, that of rolling stock and track, and the other, that of power-station plant. The discussion may be confined to conditions occurring between the hours of 5 a.m. and 11 p.m., for outside those hours traffic is and always will be negligible. The introduction of a frequent service of trains in itself tends to remove the peak and to increase the traffic in the "non-rush hours"; these hours are very insufficiently catered for at present both in train services and in attractive fares, and much can be done by the traffic officials (who I regret are not here to-night to discuss this paper) to reduce the peaks in this way. When all that can be done has been done, a peak every morning and evening will still remain, and apparently the author suggests the use of steam locomotives to smooth the peak out for the power station and for the electric plant and rolling stock. The peak for the plant is best smoothed out by the use of batteries, which not only eliminate both momentary and hourly peaks, but also are a valuable insurance and stand-by. In conjunction with batteries the efficiency curves of modern turbines and boilers are so uniformly high over a large range in the neighbourhood of full load, that both the overload at the peak and the underload at the "non-rush hours" are efficiently dealt with when reduced to a moderate range by the batteries: further, the battery plant costs no more than the extra generating plant, and enables money to be saved in feeders and sub-station plant. The provision of peak rolling stock is a more difficult matter; the author correctly points out that it is impossible to introduce the steam trains to the same platforms as the electric ones, but he does not point out what should be done with the steam locomotives during the "non-rush" period of the day. It would seem preferable to meet "rush hour" work by the use of trains with a maximum number of trailer cars, the motor cars of which will be used to maintain the frequency of service during the day with fewer trailer cars. In this way the motor cars will be kept in service and the peak rolling stock motive power provided for in the cheapest possible way; extra peak staff are also eliminated by this method. There is a loss of weight efficiency in some of the light trains in the "non-rush hours" due to the preponderance of the motor cars, but a higher acceleration can be used, and more coasting done, which will partly eliminate the loss due to carrying about the extra weight. By designing the trailers with buffers suitable for engines, these trailers can be used for seaside holiday traffic if not wanted on the electrified lines as the author suggests, though this is not the experience in the North of England. Centre corridor cars are very popular on our seaside services both for local electric trains and for such traffic as that from Manchester to Southport and Blackpool; in fact, passengers complain if compartment stock is substituted. A single wide centre door such as is used on the Tubes may be useful in corridor electric stock; but, generally speaking, for work in open country—and it is essential to go out at least 20 miles from an urban centre to make electrification financially successful—side doors are undesirable. The author rightly draws attention to the large staff required for, and the difficulty experienced in, shutting side doors on high-acceleration trains; the frequent slamming of doors also causes heavy maintenance. Further, the public who get straight into a corridor train from points marked on the platforms waste time in looking for empty compartments in compartment stock. There is no doubt that there is still a field in London and elsewhere in some specialized cases for steam-hauled suburban services. The Belgians have designed some magnificent superheater tank engines for such work, and it is not known or realized yet at how low a cost a high-speed suburban service could be worked with 2—8—2 four-cylinder tank engines with terminal facilities specially arranged for coal and water supply. Permission from the Board of Trade to work the train with the engine always at the same end

Mr. O'Brien. would be essential to the success of the scheme, and it would be quite possible to design a method of controlling the regulator from the brake van as is done on steam rail motors. The author suggests the use of semi-expresses and expresses passing stopping trains on emergency tracks; both these devices have long been in use on the Liverpool and Southport line with complete success. He is to be congratulated on a splendid and comprehensive paper on the complex subject of London urban traffic, but admirable as the paper is from a technical point of view he does not seem to have grasped the fact that it is the comparatively long-distance traffic which earns the dividend, and that the object of electrification should not be merely to fulfil the statutory obligation of conveying the people who present themselves, but rather to induce them to travel farther and more frequently. Money must be spent to make money, and empty trains may have to be run for a long time and yet pay handsomely for themselves in the long run. The author is incorrect in assuming that the length of a block section depends only on the factors which he has named; it also depends on the rate of acceleration attainable.

Mr. Bowden. Mr. J. BOWDEN: This paper is valuable and it presents many factors other than electrical which enter into electric railway operation. The freedom from electrical bias is particularly marked, but I consider that the case for electric traction is not as strongly put as it might be. The author's analysis is based upon providing seats for every passenger, a condition which does not obtain on steam suburban trains to-day and which in the comparisons of the paper is unfair to electrification. That condition may be most desirable, but it may seriously prejudice the financial aspects of an intense suburban proposition whether steam or electric. Passenger regulation is most difficult in "rush hours," and unless numbers are controlled at the barriers, passengers will stand if thereby they can travel by an earlier train. In such circumstances the public are better served by easier circulating ways and greater standing accommodation such as are found on suburban passenger cars in America. The peaks on the seats curve, Fig. 5, are responsible for heavy capital charges per train-mile in the estimate for electric working, and the author indicates still further capital charges to cover the cost of spare stock for shed and shop purposes. Shed work may be provided for during slack hours, say 10 a.m. to 4 p.m., by the stock shown to be idle in Fig. 5, and spares may thereby be reduced to those required for shop work. Steam does not lend itself to such an arrangement, which makes for lower capital and stand-by charges. In the comparison the cost of steam working is assumed at 1s. 3d. per mile, which is too low for suburban steam services. The published accounts of several railways show an approximation to that figure when all expenses and mileage (including shunting and empty stock) are taken into account; but if figures for purely suburban working were taken separately, the cost per mile would show a higher figure. In two ways therefore the estimates appear to be unfair to electric traction. The paper emphasizes such limitations to intense suburban services as are imposed by flat junctions, terminal and platform accommodation, and signalling. On the inauguration of electric traction on the Metropolitan and Metropolitan District Railways similar limitations were encountered, but up to that time they had not proved formidable owing to the restrictions Mr. B imposed by the use of steam locomotives. On the removal of these restrictions by the use of electric motors extensive developments in the permanent way and stations became necessary to meet the growing traffic, and by their adoption these railways have in conjunction with electric working been enabled to give the intense service in operation to-day. A fairer case for electric traction would have been made by the author presuming such junction and station developments. Railways are under statutory obligations favourable to suburban passengers, and London terminals will have to deal with more traffic in the future. There are no transit facilities equivalent to those provided by railways, even allowing for the possibilities of the motor omnibus, and the increased speed and frequency of service necessary cannot be given by steam without widenings, the cost of which would render them impossible. Fig. 5 indicates a poor load factor in the generating and sub-station plant. Railways working a mixed traffic could do much to fill up load-curve hollows by including shunting and goods working in the zone of electric traction. The advantages appear to be many, and there have been considerable developments abroad in this direction.

Mr. H. BURGE: On page 616 the author discusses the Mr. Bu question of side-door and end-door cars as affecting the time of stop. I should like his opinion on the corridor type of train combined with a certain number of side doors. The passengers instead of walking the length of the platform in order to find seats go in at the nearest door and look for their seats afterwards, which must facilitate rapid loading. Turning to the electrical side, the author lays great stress on the flexible speed characteristic and the necessity for low operating costs, so that any scheme using current more economically must be worth consideration. I have some figures of tests made on an underground railway on the Continent, where the ordinary traction motors were controlled by a Ward Leonard or booster set arranged on a multiple-unit system with automatic acceleration: it had evidently been adapted to the existing railway stock. For comparison two motor coaches were coupled together, No. 1 having the usual series-parallel control, and No. 2 the booster control. About 14 journeys were made, each coach doing the hauling on alternate journeys, so that the conditions were exactly similar. At the end of the tests the meters showed that the coach with series-parallel control had consumed 25 per cent more units per train-mile than the coach with booster control. It was estimated that if the booster control were used throughout the whole of that railway the saving would be over £40,000 per annum, assuming the low figure of ½d. per unit for current. Probably there would be a similar saving in the generating plant and in the feeders. The net increase in the total weight of the train so equipped was only about 3 per cent, but as the stored energy was returned on braking, the question of weight would not be important. I have a slide which gives a view of the ordinary traction motor and the Ward Leonard set alongside; the latter does not appear to take up any more space than the transformer always required for single-phase traction. The second slide shows a curve representing the number of kilowatts taken from the line. Starting on the left, the power is small, and gradually reaches about 360 kw.: then the braking commences, and

about 30 per cent of the energy used for acceleration is returned to the line. It has often been urged that the steam locomotive can fulfil conditions not yet possible with electric working, but I think it ought to be noted that this braking by returning energy to the line is something that the steam locomotive does not do.

Mr. W. M. MORDEY: I wish to follow up what I said* when Mr. Roger Smith read his paper† a few weeks ago, as to the possibility of a more economical use by the train of the energy supplied to it, especially as bearing on the comparison given in the first column of page 625 of the present paper. The uncomfortable fact is brought home to us that according to the estimates electric traction under the conditions given means an additional annual cost over steam of £15,000 for a service of 336,000 train-miles, the cost per train-mile being 26d. as compared with 15d. for steam. I want the author to consider whether a large part of this difference cannot be removed. He assumes 80 watt-hours per ton-mile for a service "to some extent of a 'non-stop' character." If this can be reduced—on what is perhaps not an unreasonable assumption—to one-half, then the 26d. will come down to 17·4d. by halving items Nos. (2) and (3), namely, 5·7d. and 11·5d., in the estimate. My suggestion for this reduction is based on general considerations of attainable efficiency and is illustrated by Fig. 1 of Mr. Roger Smith's paper. He shows how the energy per ton-mile increases as the runs become shorter, rising from 40 watt-hours per ton-mile with stations one mile apart to 80 watt-hours with stations 0·4 mile apart. This was from actual results for London suburban motor-coach trains for a schedule speed of 17 miles per hour. If Mr. Firth had been dealing with a service with stations very close together in which the energy consumption under present conditions is large, I would then also ask him to consider whether a considerable reduction is not possible. Mr. Burge has just shown a diagram which bears on the point that I previously raised and to which I should like again to refer to-night. In short-run services a very large proportion of the energy is lost in the starting resistances or is stored up in the train and lost in braking. Whether these losses can be avoided or reduced, practically and commercially, is the question. These losses are inherent to the method of control adopted; they are not inherent to electrical driving even with continuous current. Mr. Burge's diagram illustrates this point. The Ward Leonard method or any similar method offers, however, no very great advantage for "non-stop" working, and therefore would not help the author for the case with which he deals, but for other cases one may still hope that some such method may come into use. Engineers cannot be permanently satisfied with efficiencies in the neighbourhood of 25 per cent, which is probably as much as is now reached on the average. I refer of course to the efficiency of propulsion calculated on the energy actually spent in directly overcoming train resistance, and bearing in mind that 1 lb. friction per ton needs at 100 per cent efficiency 2 watt-hours per ton-mile.

Mr. H. G. DRURY: There is no difficulty in carrying the traffic by steam at the hours of the day when there is no rush, but even with the additional attractions of electrical working I think it is extremely doubtful whether at those hours of the day sufficient traffic could be withdrawn from the roads to warrant the expenditure of a large amount of capital. For suburban traffic and for such traffic as that on the Metropolitan and Metropolitan District Railways electric traction is the ideal motive power.

Mr. H. W. FIRTH (*in reply*): Mr. Smith emphasized one point which he attributes to Mr. Aspinall, viz. that for electrification to be successful it is necessary to choose the right locality. I have tried to emphasize that feature in the paper. I have pointed out that the results which can be obtained from electrification must be very carefully considered with regard to the kind of district that is being served. That also answers another point raised by Mr. O'Brien with regard to improving the load factor, in which he instanced the Liverpool–Southport traffic. With all due respect to Mr. O'Brien, however, although the traffic officers of the Lancashire & Yorkshire Railway are very able men, I think that the enormous increase of traffic on that line is not entirely due to the work of those officers. On page 620 of the paper I myself have mentioned that particular service as an instance. When there is a big town at one end of the line and a fine seaside resort at the other, with a number of golf links and seaside resorts between, as well as a big residental district, that is a service which is simply crying out for electrification. When a service of that kind is compared with a tapering London suburban service, starting at a terminus and going down to a little place in the suburbs, with perhaps two or three passengers for the train, and no all-day attractions, we are not comparing like with like. I fully agree with the remark of Mr. Aspinall, which I had not noticed before, that the right locality must be chosen, and that point is strongly emphasized in this paper.

Mr. Smith issues a warning against carrying the analogy of peak-load supply in power work too far; he also rather criticized the use of the term "load factor" as applied to railway traffic. I particularly used the term "load factor" because I wanted to make this analogy, and because "load factor" is a term which is so greatly used by all of us in our work. I thought, therefore, it would convey the best idea of what I wanted to discuss without attempting to introduce a new unit. The term "load factor" must of course be used with care, but used in the way that I have used it in the paper I think it conveys what I want it to convey.

Mr. Smith also mentioned, with regard to the first five pages of the paper, that the ideal appeared to be to have at least one separate pair of tracks confined to and signalled for suburban traffic alone. That is all very well; but, as I mentioned in the paper, with bad-load-factor traffic one is faced with the difficulty that if a separate pair of tracks is provided, so signalled as to provide specially for suburban services, one is then introducing a line which is not available, or at any rate not so available, to take other traffic. It is a very nice arrangement indeed, but very expensive, and I think that with bad-load-factor traffic, such as I have been particularly emphasizing, it would absolutely be put out of court on the question of expense. Mr. Smith mentioned as an instance that the London & North-Western Railway have separate lines; but as I am not very familiar with the latest developments on their new line, I should like to ask Mr. Smith whether he can tell me if these new

* *Journal I.E.E.*, vol. 52, p. 371, 1914.

† R. T. SMITH. Some railway conditions governing electrification. *Journal I.E.E.*, vol. 52, p. 293, 1914.

Mr. Firth. lines are to be signalled exclusively for suburban working, or whether they are being signalled so that they can be used, if required, for general traffic.

In regard to the question of costs, Mr. Smith asked whether the 15d. given in the paper was an estimate or whether it was based on actual working; he also said that it is too low, and that capital charges on locomotives should be included. As I say in the paper, the figures are not put forward as estimates of actual operating costs in any particular case, but have been taken as a fair average. I think that the published reports of the companies show that 15d. is a fairly good figure, taking main lines, goods working, suburban working, and everything else; and if one remembers that peak-load suburban traffic is to a large extent non-stop or semi-non-stop in character, I think it will be agreed that 15d. is a fairly reasonable figure. Anyway, perhaps it has not been borne in mind that in arriving at the 26d. which I have given for peak electric service I have not debited the electrical cost of operating that peak with all the figures that it ought to have set against it. To my mind those extra charges would certainly offset the locomotive capital charges, more especially as these are small, and it is assumed that the locomotives could be used to a considerable extent in other services as well as in the peak-load service, so that the proportion of capital charges of the locomotive to be charged to the suburban working is quite a small figure per train-mile. The instance which Mr. Smith mentioned of a mixed service is quite interesting. It is operated, as he pointed out, by two companies, one controlling the steam service and the other the electric; so that it is not quite on all fours with the suggestion that I made.

With regard to Mr. O'Brien's remarks, I have dealt above with his point about the possibility of improving the load factor. To amplify that slightly, it is greatly dependent on the type of district involved. Undoubtedly a great deal can be done, and has been done, by traffic officers to improve the load factor, but in my opinion the success of their efforts depends very largely indeed on the nature of the district. Mr. O'Brien also rather criticized the feasibility of working a mixed traffic of steam and electric trains into terminal stations. The last two paragraphs in the first column of page 620 of the paper, however, sufficiently deal with that point. I am assuming that these "rush-hour" steam trains would be dealt with more or less on the other spare main-line platforms. As to the use of trailer cars as a possible solution, surely one has to pay either in meal or in malt, as the lawyers say, for the transportation equipment. If all the apparatus is placed on a fewer number of motor cars it is still necessary to haul practically the same weights, and to perform the same schedule; and, as Mr. O'Brien himself mentioned, the equipment at the "non-rush hour" times would be less efficient and it may be that the train is not so capable of being split up into the right-sized smaller trains for "non-rush hours." Although it is worth consideration in some cases, I think that it would not entirely meet the case in respect to intense rushes.

With regard to the question of the use of superheat for steam suburban services, I was very interested to hear the remarks on that point from the representative of a railway which has done a very great deal in regard to superheating, as I have always understood that superheating for steam locomotives on suburban services with many stops was an extremely difficult subject. Mr. O'Brien asked if the length of block section does not depend on the acceleration rate of the train. I think that that is not so. The time of clearing the section is dependent on the acceleration to some extent, but the length of block section depends on the length of the train. It is the length of train, not the time taken to cover the distance, which is the limiting factor as to the length of the block section; but the acceleration does largely influence the time it is in that block section. [Mr. O'Brien: The acceleration influences the length of the block section, because it influences the maximum speed. The higher the acceleration, the greater is the maximum speed that it is possible to obtain between one block section and another.] I had more in my mind the question of block section length at a station than that point. In a through run of course the acceleration does affect it, because it affects the maximum speed, but the limiting point is really the station block length, and there it is necessary to cover the length of the train.

Then Mr. O'Brien made the point that passengers can be taught to enter the car at the rear end and to go out by the head end. All I can say is that I believe that was tried on the London tubes: as to whether it has been successful, I will leave the audience to judge.

I was very interested in Mr. Burge's remarks on the question of utilizing the Ward Leonard control. If the figures that he put forward can be justified in practice, if the weight can be kept down, and if there are no other difficulties, the 25 per cent saving will certainly be a very great point indeed. I take it that Mr. Burge has assured himself that the characteristics of this arrangement would be suitable for the various classes of traffic that I have mentioned. I have not seen any curves or figures as to what this equipment actually does, but I am glad to see that it is a matter in which other people are taking an interest.

Then Mr. Bowden said that I did not make out a sufficiently strong case for electrification. I am sorry if that is so. I have tried to put down here some of the facts as they appeal to me, and I must leave them to be their own justification. As to the possibility of mitigating the bad load factor by using the spare time for shed purposes, the amount of time which can be utilized efficiently in that way is, I think, very small indeed.

Mr. Mordey's remarks were very much to the point. I quite agree with him that the energy is not utilized in the present equipments as it ought to be. As to the 80 watt-hours per ton-mile mentioned in the paper, I think that that is not much too high if one remembers that the "rush hour" business is only partially non-stop, and that at any rate a number of the trains at "rush hours" must be stopping trains. If one takes service conditions and not test conditions I think that 80 watt-hours per ton-mile is not too high.

On the question of capital charges Mr. Smith criticized my figure of 10 per cent and said that it ought to be 7 per cent. Of course, one can make a case anything that one wishes by taking appropriate figures, but I think that at any rate as regards rolling stock 10 per cent is not too much to allow for capital charges, including depreciation and obsolescence. I want to emphasize that these are not

Mr. Firth. to be taken as hard and fast figures for any particular case. They are not put down as absolute estimates, but merely as giving some fairly good idea of what this peak service means. If my figures are 50 per cent wrong I still maintain that that peak service, on the basis of present fares and on the basis of providing a seat for every passenger at "rush hours," does not appear to be a financially attractive proposition.

Mr. Bowden has criticized the suggestion of providing seats for every passenger during "rush hours," and has said that steam railway companies do not do it. They do not always do so, but at any rate they are certainly not behind the electric tube railways and other similar railways in that respect, and they certainly do try to provide a seat for each passenger. Perhaps one point in which we fail is that we do not provide straps in our cars for the people who cannot find a seat.

In conclusion, I am an enthusiast for electric traction whenever the load factor conditions or the utility factor conditions are satisfactory, or can be made satisfactory. It is no good ignoring facts, however, and the facts in relation to heavy-peak "rush hour" traffic are not easy to get over. If by reducing the energy consumption and also the capital cost, by improving the efficiency and by improving methods generally, we can reduce the cost of operating those peak services, nobody will be more delighted than I shall be; and if this discussion has emphasized the point sufficiently, so that competent people will take up the question, reduce the cost, and improve the mechanism for operating these peak-load services, I shall certainly not have written this paper in vain.

Communicated: I should like to deal with several of the points raised in the discussion which lack of time prevented my replying to verbally.

Mr. Roger Smith refers to Mr. Aspinall's remarks as to combined steam and electric working on the Liverpool–Southport line while the work of electrification was being carried out; but I would point out that this was the service in which the attempt was made—and necessarily made—during the transition period to carry out the same schedule with steam trains as was being worked by the electric trains. This is explained by Mr. Aspinall in the Address in which the figures quoted by Mr. Smith are given, and the remark is made that the excessive fuel consumption of the locomotives was due to the high acceleration required. This is a type of service quite different Mr. Firth. from the combined working suggested in the paper, in which it is assumed that to a considerable extent at any rate the steam "rush hour" trains can be operated on main-line tracks, as is largely the case at present, so that the speed characteristics on any given track can be kept much the same. The paper has emphasized the difficulties of intermingling trains of widely varying speed characteristics on the same track.

The author agrees that the figure of 15d. per train-mile is too low for general heavy suburban service, but he is of opinion that it is a reasonable figure to assume for that peak-load portion of the suburban service which has been mentioned, a considerable proportion of which calls for fairly long runs with stops therefore comparatively far apart and conditions which are not particularly onerous.

With regard to Mr. O'Brien's remarks as to storage batteries, while these are undoubtedly valuable in smoothing the peaks at the power station, their efficiency is not high and the depreciation and maintenance costs are comparatively heavy. The author thinks that with widely divergent demands for power, such as would be made by traffic having the characteristics shown in Fig. 5, batteries would not be of great assistance, or at any rate that their use would not materially reduce the capital and operating costs taken together much below those assumed in arriving at the figure of 26d.

Mr. O'Brien makes a criticism that the author "does not seem to have grasped the fact that it is the comparatively long-distance traffic which earns the dividend, and that the object of electrification should not be merely to fulfil the statutory obligation of conveying the people who present themselves, but rather to induce them to travel farther and more frequently." In answer to this, the author would point out that he has specifically called attention on page 610 to such services as the London–Brighton, London–Clacton, London–Southend, and has emphasized the point that in considering the line of demarcation between the main-line and suburban services the character of the traffic is of importance and not merely the distance; and further he has stated that the outer-suburban traffic must be carefully considered, whatever its length of run, because of the great possibility of obtaining by electrical means a considerably increased revenue.

REPORT OF THE COUNCIL FOR PRESENTATION AT THE ANNUAL GENERAL MEETING OF 21st MAY, 1914.

At this, the Forty-second Annual General Meeting of The Institution of Electrical Engineers, the Council present to the members their Report for the year 1913–14.

Membership of the Institution.

The changes in the membership since the 1st May, 1913, are shown in the following table :—

	Hon. Mem.	Mem.	Assoc. Mem.	Assoc.	Grad.	Stu.	Totals.
Totals at 1st May, 1913	7	1,549	3,535	671	260	1,062	7,084
Additions during the year :—							
Elected ...	—	13	74	5	32	163	287
Reinstated..	—	4	6	1	2	2	15
Transferred to ...	1	22	50	2	33	—	108
Total ...	1	39	130	8	67	165	410
Deductions during the year :—							
Deceased ...	—	21	12	8	—	3	44
Resigned ...	—	12	35	21	5	37	110
Lapsed ...	—	5	48	23	1	110	187
Transferred from ...	—	2	15	11	6	74	108
Total ...	—	40	110	63	12	224	449
Net Decrease							39
Totals at 1st May, 1914 :—	8	1,548	3,555	616	315	1,003	7,045

In addition, 112 candidates for Associate Membership have been approved by the Council for admission to that class on condition that they pass the Institution examination or otherwise satisfy the examination regulations. Of these, 2 are Associates, 29 Graduates, 11 Students, and 70 non-members.

Members Deceased.

It is with deep regret that the Council have to record the death, on the 6th November, 1913, of Sir William Henry Preece, K.C.B., F.R.S. Sir William, who was one of the original members of the Institution, was at the time of his death the senior surviving Past President, having been first elected to that office in 1880, after serving successively as Member of Council and as Vice-President from the year 1873. He served a second year of office as President in 1893.

Among other well-known members who have died during the last twelve months are Mr. Charles Thomas Fleetwood (Member of Council, 1879–80), Mr. Alfred S. Giles (Chairman of the Cape Town Local Section, 1906–7), Mr. John Gott, Mr. John Wykeham Jacomb-Hood (Member of Council, 1907–10), and Colonel Matthew Townsend Sale, R.E., C.M.G. (Member of Council, 1879–80 and 1888–9).

The complete list of those who have died during the past session is as follows :—

Members.

Alfred Apps.
Thomas Blissett.
Frederick Brown.
James Herbert Cawthra.
Thomas Cushing.
William Tregarthen Douglass.
Robert Steuart Erskine.
Stephen D. Field.
Charles Thomas Fleetwood.
Alfred S. Giles.
John Gott.
John Wykeham Jacomb-Hood.
Francis Valentine Toldervy Lee.
William Francis Melhuish.
Henri Menier.
Hatsune Nakano.
Walter Ambrose Pearson.
Sir William Henry Preece, K.C.B., F.R.S.
Colonel Matthew Townsend Sale, R.E., C.M.G.
William Rowan Wilson.
George Alexander Zeden.

Associate Members.

James Russell Allport.
William Walne Alston.
Burdett Wyke Bayliss.
George Stratton Cross.
Henry Farmer.
Nigel Cuthbert Espir Hall.
Lieut.-Colonel James Walker Ormiston, R.A.
George Henry Phillips.
Tyson Sewell.
Ernest Sykes.
Sydney Woodfield.
Reginald Choldmeley Campbell Yates.

Associates.

Frederick E. Evans.
Andrew L. Lind.
Johan Mygind.
Joseph Giammusso Oliveri.
Walter Pethybridge.
John Guy Pointon.
Antolin Ruiz.
Alfred Smith.

Students.

Ronald Graham Hargraves.
Leslie Bromley Moulson.
William Arthur Adamson Page.

Meetings and Papers.

During the past twelve months 15 Ordinary Meetings and 17 Council Meetings have been held. The usual Standing Committees have met regularly, and there have also been meetings of other Committees appointed by the Council for the consideration of special matters, the total number of Committee Meetings held during the year being 127.

There have been 62 meetings of Local Sections, viz. Birmingham Local Section 11, Dublin Local Section 6, Manchester Local Section 12, Newcastle Local Section

12, Scottish Local Section 8, Western Local Section 5, and Yorkshire Local Section 5.

Meetings have also been held of the Calcutta and Cape Town Local Sections.

ANNUAL DINNER.

The Annual Dinner of the Institution took place at the Hotel Cecil, London, on the 5th February, 1914. A report of the proceedings will be found in the *Journal*, vol. 52, p. 378.

KELVIN LECTURE.

The fifth Kelvin Lecture was delivered by Sir Oliver Lodge, D.Sc., F.R.S., on the 22nd January last, the subject of the lecture being: "The Electrification of the Atmosphere, Natural and Artificial." (*Journal*, vol. 52, p. 333.)

JOINT MEETING IN PARIS WITH THE SOCIÉTÉ INTERNATIONALE DES ÉLECTRICIENS.

A very successful joint meeting with the Société Internationale des Électriciens was held in Paris from the 21st to the 24th May, 1913. A full account of the proceedings will be found in the *Journal* (vol. 51, p. 481).

PREMIUMS.

The following premiums for papers have been awarded by the Council this year. In accordance with precedent, in deciding upon these awards the Council have not taken into account papers contributed wholly or in part by Members of Council.

The INSTITUTION PREMIUM, value £25,

to Mr. S. Evershed, for his paper, "The Characteristics of Insulation Resistance."

The AYRTON PREMIUM, value £10,

to Mr. F. Lydall, for his paper, "Electric Locomotives."

The FAHIE PREMIUM, value £10,

to Commandant G. A. Ferrié, for his paper, "Application of Wireless Telegraphy to Time Signals."

The JOHN HOPKINSON PREMIUM, value £10,

to Mr. L. J. Hunt, for his paper, "The Cascade Induction Motor."

The PARIS PREMIUM, value £10,

to Mr. B. Welbourn, for his paper, "British Practice in the Construction of High-Tension Overhead Transmission Lines."

AN EXTRA PREMIUM, value £10,

to Messrs. K. M. Faye-Hansen and J. S. Peck, for their paper, "Current-Limiting Reactances on Large Power Systems."

AN EXTRA PREMIUM, value £5,

to Mr. S. H. Holden, for his paper, "The British Standard Specification for Consumers' Electric Supply Meters."

AN EXTRA PREMIUM, value £5,

to Mr. F. J. Teago, for his paper, "Experiments on Air-Blast Cooling of Transformers.

STUDENTS' PREMIUMS.

A STUDENTS' PREMIUM, value £10,

to Messrs. E. A. Richards and D. Dunham, for their paper, "Comparative Tests on Single-Phase A.C. Commutator Motors."

A STUDENTS' PREMIUM, value £7.

to Mr. H. S. Ripley, for his paper, "The Electrical Equipment of Collieries."

A STUDENTS' PREMIUM, value £5,

to Mr. J. Lindley Thompson, for his paper, "Diseases and Troubles experienced with Transformers."

A STUDENTS' PREMIUM, value £5,

to Mr. J. L. Moffet, for his paper, "The Possibilities of Electric Traction on Railways."

A STUDENTS' PREMIUM, value £5,

to Mr. W. S. Flight, for his paper, "The Laws of Dielectrics."

A STUDENTS' PREMIUM, value £5,

to Messrs. A. Arnold and E. L. M. Emtage, for their paper, "The Automatic Control of Electrical Generators by means of Automatic Pressure Regulators."

SCHOLARSHIPS.

The Council have awarded a Salomons Scholarship of the value of £50 to Mr. C. H. Stubbings, of King's College, London; and two David Hughes Scholarships of the value of £50 each, one to Mr. John G. Wellings, of the City and Guilds of London Technical College, Finsbury, and one to Mr. James Mould, of University College, London.

STUDENTS' SECTIONS.

Nine meetings of the Students' Section have been held, at which papers were read and discussed. At the opening meeting an address to the Students was delivered by Dr. C. V. Drysdale in the Lecture Theatre of the Institution (*Journal*, vol. 52, p. 286).

The Annual Dinner was held at the Trocadero Restaurant, London, on the 8th December, 1913.

The Manchester, Newcastle, and Scottish Students' Sections have each completed a successful session, having held ten, six, and five meetings respectively. Visits were made to various works by the kind permission of the firms concerned.

"SCIENCE ABSTRACTS."

In 1913, as in the previous year, the Physics Section shows a small increase in size: the volume comprises 2,022 Abstracts as compared with 1,916 in 1912. The Electrical Engineering Section, on the other hand, contains the same number of pages as in 1912.

Several additional transactions and periodicals have been added to those which are regularly reviewed. A list of these is given in the Index to the 1913 volume.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

A meeting of the International Electrotechnical Commission was held at Berlin from the 1st to the 6th Sep-

tember, 1913, at which the British Committee was represented by Mr. Alexander Siemens (President of the Committee), Colonel R. E. Crompton, C.B., Mr. W. Duddell, F.R.S., Mr. A. R. Everest, Mr. L. Gaster, Dr. Gisbert Kapp, Professor T. Mather, F.R.S., Mr. F. H. Nalder, Mr. G. Stoney, F.R.S., Dr. S. P. Thompson, F.R.S., and Mr. P. F. Rowell (Secretary).

The next plenary meeting of the Commission will take place at San Francisco in September, 1915.

The Council desire to draw the attention of members to the decisions of the Commission adopted at the Berlin meeting :—

Symbols.

The recommendations of various Special Committees by whom this subject had been dealt with from time to time were considered, and the final recommendations in the form adopted by the Commission will be found in Publication 27 issued in January, 1914, by the Central Office of the Commission.

Rating of Electrical Machinery and Apparatus.

The adoption of an upper limit for the cooling-air temperature was discussed, and further action was deferred until the next plenary meeting.

Nomenclature.

A list of some 80 terms and definitions was adopted, and it was decided to undertake the consideration of others applicable to electromotive forces and differences of potential in single or polyphase alternating-current systems.

Prime Movers.

A number of definitions were approved relating to hydro-electric installations.

Industrial Committee.

The Council have to report that the Industrial Committee has been dissolved.

This Committee was constituted on the 28th March, 1912, and then consisted of six Members of Council, twelve members of the Institution not being necessarily Members of Council, and six other persons not being necessarily members of the Institution. On the 14th November, 1912, the members of the Committee not being members of the Institution were increased from 6 to 12 in number. Representatives of the Tramways and Light Railways Association, the Association of Electric Power Companies, the British Electrical and Allied Manufacturers' Association, the Incorporated Municipal Electrical Association, the Conference of Chief Officials of the London Electric Supply Companies, and the Association of Municipal Corporations, accepted seats on the Committee.

The work of the Parliamentary Committee of the Institution which had hitherto dealt with legislative and similar subjects was transferred to the Industrial Committee.

The constitution of the Committee was framed so as to secure the widest representation of the industry, and with a view to the accomplishment of effective work by utilizing the organization and influence of the Institution. The powers conferred upon the Committee were very carefully considered with a view to the attainment of the maximum benefit from its operations, and the Council hoped for much good from the Committee's deliberations and recommendations. In common with other Committees of the Institution the Industrial Committee was required to report to the Council by whom such action would be taken as they might consider advisable. The constitution and powers of the Committee will be found in the Annual Report for 1911–12 (*Journal*, vol. 49, p. 664).

Fourteen meetings of the Committee have been held, at which the matters considered were the Electric Lighting Bill (1912), the National Insurance Act, the draft Census of Production Schedules, and the Sheffield Corporation Bill (1912).

On the 9th March last, the Committee reported to the Council as follows :—

"The Industrial Committee have carefully considered the constitution of the Committee and the powers conferred upon it by the Council of the Institution.

"They are unanimously of opinion that it is not only desirable, but of importance to the electrical industry, that an organization should exist which is capable of protecting and promoting the legislative and industrial interests of the industry, in so far as these interests are not already represented, protected, and promoted by the various existing Associations, and also for the purpose of co-ordinating and supporting the work of these sectional associations.

"They are of opinion that the present constitution and powers of the Industrial Committee are not such as to enable it to perform useful work. They are further of opinion that the views of the Council of the Institution should be ascertained as to whether it is advisable to enlarge the powers of the Industrial Committee and give it the necessary authority effectively to carry out the work referred to; or, alternatively, as to whether the Council be of the opinion that the consideration of these industrial questions is properly within the province of the Institution."

On the question of enlarging the powers of the Industrial Committee, the only additional powers would have been the granting of plenary authority to act independently of the Council, but no such extension of powers could be given, as the Council cannot wholly delegate to a Committee the powers or authority vested in them by the members of the Institution. Neither were the Council able to suggest any advantageous change in the constitution of the Committee, and in view of the opinion of the Committee as expressed in their Report there was no alternative but to dissolve the Committee.

The Council take this opportunity to point out the grave difficulties which arise if questions are dealt with which involve matters of a political character or in regard to which the interests of various sections of the membership may be in conflict.

With regard to the Council's attitude towards industrial questions, the Council will in future, as in the past, within the provisions of the Memorandum of Association, take such action in respect of legislative or industrial matters as may conduce to the general advancement of electricity and its applications, and will give full consideration to any representations made to them while preserving impartiality to all sections of the electrical industry.

Municipal Loans.

The Council have recently appointed a Committee to consider and report on the question of the duration of municipal loans, and whether it is advisable to approach the Local Government Board in relation thereto.

Meetings for Specialized Papers.

In view of the development of electrical engineering and the consequent greater specialization among the members, the Council have had under consideration the question whether by some reorganization of the meetings interest in the different branches can be stimulated so as to encourage the members to take a more active part in discussions on the subjects which are of special interest to them.

It will be remembered that the Council had a similar object in view when it was decided to hold "Informal Meetings," but the only meetings held under that scheme were not of the kind indicated above and on the whole therefore did not fulfil their purpose.

The tendency to form new societies dealing with special branches shows that there is a real demand for meetings at which specialized subjects can be considered and discussed, and the excellence of the papers obtained by some of the smaller societies indicates that authors are willing to write papers for a specialized audience.

The proper body to organize meetings for all the branches of the electrical engineering profession is the Institution, and the Council have accordingly appointed a number of Sectional Committees, each of which will be intimately connected with some particular section of electrical engineering and whose duty will be to advise the Council as to the selection of papers and promotion of discussions of a specialized nature likely to be of interest to those engaged in that particular section.

Local Centres Abroad.

The Council are of opinion that it would be in the best interests of the Institution to extend its influence by the formation of Local Centres abroad for the purpose of reading papers and for discussions on electrical subjects. Local Centres already exist at Calcutta and at Cape Town, and recently the Council sanctioned the formation of a Centre at Hong Kong. The Council will accordingly be glad to hear on this subject from members residing abroad in places where such Centres might be established.

The Council are highly gratified at the successful meetings held at the Calcutta Centre.

Research.

The Council have placed a sum of £500 at the disposal of the Research Committee for the year 1914 for work in connection with Magnet Steels, the Heating of Buried Cables, and the Properties of Insulating Oils. An outline of the proposed investigation will be found in the *Journal* (vol. 52, p. 47).

Kelvin Memorial Fund and Medal.

The Memorial Window to Lord Kelvin, subscribed for by engineers of the British Empire and Dominions and of the United States of America, has been placed in Westminster Abbey and was dedicated there on the 15th July, 1913. The ceremony was attended by a large number of engineers, including representatives of all the Engineering Societies whose members had taken part in the provision of the Memorial, and by representatives of Glasgow University and Peterhouse College, Cambridge.

The receipts in connection with the Memorial amounted to £1,690 13s. 6d., and the disbursements were £1,222 19s. 7d., leaving a balance in hand of £467 13s. 11d. The Council have agreed to the suggestion of the Executive Committee of the Fund that this balance be disposed of in the following manner :—

(*a*) A Kelvin Gold Medal to be established for award triennially as a mark of distinction achieved in engineering work of the kinds with which Lord Kelvin was especially identified.

(*b*) The award to be made on each occasion after consideration of recommendations to be invited from the principal engineering societies in all parts of the world.

(*c*) The award to be dealt with by a Committee in London, to consist of the Presidents for the time being of the Institution of Civil Engineers, the Institution of Mechanical Engineers, the Institution of Electrical Engineers, the Institution of Naval Architects, the Iron and Steel Institute, and the Institution of Mining and Metallurgy.

(*d*) The Institution of Civil Engineers to be requested to accept the custody and trust of the Medal Fund.

International Illumination Commission.

The Council have decided to take part in the International Illumination Commission by appointing delegates to the British National Committee and by contributing equally with the Institution of Gas Engineers and the Illuminating Engineering Society towards the expenses of this Committee.

The following delegates have been appointed by the Council to represent the Institution :—

Mr. W. Duddell, F.R.S.

Mr. F. Bailey.	Mr. Haydn T. Harrison.
Mr. K. Edgcumbe.	Professor J. T. Morris.

International Scientific Radio-Telegraphic Commission.

In October last the President reported to the Council that he had recently taken part in an international conference at Brussels with regard to the formation of an International Commission to carry out scientific experiments in wireless telegraphy, the intention being that the Commission should be on the lines of the International Electrotechnical Commission and that National Committees (one for each country taking part) would send delegates to the central body. The President also informed the Council that owing to the generosity of Mr. Goldschmidt, of Brussels, the use of a large wireless station and the sum of 50,000 francs had been placed at the disposal of the Commission, and that it was proposed in the first place to make measurements of the strength of the signals sent out from Brussels. The National Committee would in each country organize the method of making the measurements and arrange with experimenters to carry them out.

It was resolved that the Institution undertake the responsibility of forming the National Committee for the United Kingdom, which has accordingly been constituted by the Council as follows :—

British National Committee (I.S.R.T.C.).

Mr. W. Duddell, F.R.S.

Dr. W. H. Eccles.	Dr. E. W. Marchant.
Professor G. W. O. Howe.	Sir Henry Norman, M.P.
Sir Oliver Lodge, D.Sc., F.R.S.	Dr. S. P. Thompson, F.R.S.

The first meeting of the Commission was held in Brussels on the 6th April last, and the British National Committee was represented on this occasion by Mr. W. Duddell, F.R.S., Dr. W. H. Eccles, and Dr. E. W. Marchant.

Engineering Standards and British Electrotechnical Committees.

A re-organization of the Electrical Section of the Engineering Standards Committee and of the British Electrotechnical Committee on the following lines has been approved by the Council and the Engineering Standards Committee :—

(*a*) The number of representatives of the Institution on the Engineering Standards Committee to be increased from two to three.

(*b*) In place of the existing Electrical Plant Committee of the Engineering Standards Committee an Electrical Sectional Committee thereof to be formed, representative of every electrical interest and containing a predominating representation of the Institution.

(*c*) In future the Engineering Standards Committee, in consultation with the Institution, to appoint the British Electrotechnical Committee, with the understanding that the members of the Electrical Sectional Committee constitute in the first place the British Electrotechnical Committee as re-organized.

(*d*) The Engineering Standards Committee to be responsible for the funds necessary for conducting this work and for the expenses of the British Electrotechnical Committee.

The representatives of the Institution on the Engineering Standards Committee are Colonel R. E. Crompton, C.B., Mr. J. F. C. Snell, and Mr. C. P. Sparks.

Model General Conditions for Contracts.

The revised Model Conditions have been approved by the Council and were published on the 1st May, 1914.

Benevolent Funds.

The Committee of Management report that the Benevolent Fund of the Institution shows a satisfactory increase for the past year. On 31st December, 1913, the capital account of the Fund stood at £4,642 3s. The donations and subscriptions to the Fund in 1913 amounted to £153 15s. 6d. The Council desire to acknowledge their indebtedness to the generosity of the donors and subscribers who have supported the Fund.

The Wilde Benevolent Trust Fund stands at £1,846 4s. 6d.

Annual Accounts.

Excess of Income over Expenditure.—The margin to the good on the Revenue Account, £2,832 12s. 3d., carried to the credit of the General Fund, compares with £1,237 19s. 5d. in 1912.

Mortgages—

	£	s.	d.
In the Accounts for 1912 these stood at	35,621	18	2
Amount of repayment during the year	680	11	3
They now stand at	£34,941	6	11

Life Compositions Fund.—The amount received during 1913 was £86 6s., bringing the total of the Fund to £5,560 9s. Out of this the sum of £53 10s. has been transferred to the General Fund, in accordance with the Articles of Association, on account of Life Compositions of deceased members, leaving to the credit of the Fund £5,506 19s.

Of this amount, £5,332 2s. 10d. is invested in Stock Exchange securities.

Building Fund.—This has been augmented during the year by—

	£	s.	d.
Donations, Subscriptions, etc. ...	112	9	0
Contribution out of Institution Revenue	568	2	3
	£680	11	3

which amount was utilized in reduction of the Economic Life Assurance Society's mortgage.

Assets.—Taking the Tothill Street property and the Investments at cost, and the Institution Building and Lease, the Library and Furniture, etc., at the values standing in the books after writing off depreciation—

	£	s.	d.
the Assets amount to	114,001	1	4
against Liabilities	44,781	8	4
leaving a margin to the good of	£69,219	13	0

which is made up as follows :—

	£	s.	d.
Building Fund	42,495	14	11
Life Compositions Fund...	5,506	19	0
Kelvin Lecture Fund ...	862	10	10
Reserve for Repairs ...	183	3	2
General Fund	20,171	5	1

	£	s.	d.
This margin set against the margin to the good in 1912 of	65,217	9	10
shows an improvement for 1913 of	£4,002	3	2

Library.

Seventy-two new books have been purchased since April, 1913, and 238 books and pamphlets have been presented by members, non-members, and publishers. The total number of readers during the past twelve months was 1,557, of whom 223 were non-members. The thanks of the Institution are again due to Mr. R. K. Gray, who

continued to pay the wages of a skilled book repairer engaged in repairing the old bindings in the Ronalds and the Institution Libraries.

The trustees of the Ronalds Library held their annual meeting, as provided for in the Trust Deed, in February last, and after inspecting the books stated that in their opinion the terms of the Trust Deed had been carried out by the Institution in a satisfactory manner.

In February last the catalogue of the Lending Library was issued to members. The catalogue contains 634 entries of works selected by the Library Committee for purchase, and during the two months which have elapsed since the formation of the Lending Library 306 issues of books to members have been made. These figures are gratifying to the Council, and it is hoped that members will continue to make use of this branch of the Library.

Museum.

Numerous additions, among which are the following, have been made to the collection of historical apparatus :—

Articles presented	Donors
Specimens of early telegraph cables and miscellaneous electrical apparatus from the collection made by the late Sir William Preece.	Family of the late Sir William Preece
A collection of high candle-power carbon filament lamps and collars.	Edison and Swan United Electric Light Co., Ltd.
A telephone used in the winter quarters of the British Antarctic Expedition, 1910–12.	F Gill
Sir William Fothergill Cooke's two original telegraph needles, electric alarm clock, and original specification and patent grant for the telegraphic apparatus patented by Sir William Fothergill Cooke and Sir Charles Wheatstone.	Grandchildren of the late Sir William Fothergill Cooke (Mrs. A. F. Grimley, Mrs. Jenkins, Major W. F. Cooke Tayler, and Mr. G. R. Tayler)
A collection of fuses patented by Sir William Thomson, and a Kapp and Crompton potential indicator.	K. Hedges
An early Wilde dynamo.	P. Huddleston
A reproduction of the original telephone invented by Alexander Graham Bell in 1875.	J. E. Kingsbury
A Dahl electric motor.	W. M. Mordey
An early telephone switchboard.	Norwegian Telegraphs Department

APPENDIX TO REPORT.

TRANSACTIONS, PROCEEDINGS, ETC., RECEIVED BY THE INSTITUTION.

BRITISH.

British Association for the Advancement of Science, Reports.
Cambridge Philosophical Society, Proceedings.
Chartered Institute of Patent Agents, Transactions.
Faraday Society, Transactions.
Greenwich Magnetical and Meteorological Observations.
Incorporated Institution of Automobile Engineers, Proceedings.
Incorporated Municipal Electrical Association, Proceedings.
Institute of Chemistry, Proceedings.
Institute of Marine Engineers, Transactions.
Institute of Metals, Journal.
Institution of Civil Engineers, Proceedings.
Institution of Engineers and Shipbuilders in Scotland, Transactions.
Institution of Mechanical Engineers, Proceedings.
Institution of Mining and Metallurgy, Transactions and Bulletin.
Institution of Naval Architects, Transactions.
Institution of Post Office Electrical Engineers, Papers.
Iron and Steel Institute, Journal and Carnegie Memoirs.
Liverpool Corporation Tramways, Annual Reports.
Liverpool Engineering Society, Proceedings.
Manchester Literary and Philosophical Society, Memoirs and Proceedings.
Municipal School of Technology, Manchester, Journal.
National Physical Laboratory, Reports and Collected Researches.
North-East Coast Institution of Engineers and Shipbuilders, Transactions.
North of England Institute of Mining and Mechanical Engineers, Transactions.
Physical Society, Proceedings.
Röntgen Society, Journal.
Royal Dublin Society, Scientific and Economic Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Quarterly Journal and Monthly Notes.
Royal Society, Philosophical Transactions and Proceedings.
Royal Society of Arts, Journal.
Royal Society of Edinburgh, Transactions and Proceedings.
Royal United Service Institution, Journal.
Rugby Engineering Society, Proceedings.
Society of Chemical Industry, Journal.
Society of Engineers, Transactions.
South Wales Institute of Engineers, Proceedings.
Surveyors' Institution, Transactions and Professional Notes.
Tramways and Light Railways' Association, Journal.

COLONIAL.

Australian Official Journal of Patents.
Canada, Department of Mines, Mines Branch, Reports.
Canadian Society of Civil Engineers, Transactions.
Engineering Association of New South Wales, Proceedings.
Engineering Society of Toronto, Transactions.
Indian Telegraph Department, Administration Reports.
Royal Society of Victoria, Proceedings.
South African Institution of Electrical Engineers, Transactions.
South Australia, Meteorological Observation Reports.
Western Australian Institution of Engineers, Proceedings

AMERICAN.

American Academy of Arts and Sciences, Proceedings.
American Electrochemical Society, Transactions.
American Institute of Electrical Engineers, Transactions and Proceedings.
American Institute of Mining Engineers, Transactions.
American Philosophical Society, Proceedings.
American Society of Civil Engineers, Proceedings.
American Society of Mechanical Engineers, Journal.
Bureau of Standards, Washington, Bulletin.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
Illuminating Engineering Society, N. Y., Transactions.
National Electric Light Association, Transactions.
Smithsonian Institution, Reports.
U.S. Official Patent Gazette.
U.S. Ordnance Report.
Western Society of Engineers, Journal.

AUSTRIAN.

Kaiserliche Akademie der Wissenschaften, Wien, Sitzungsberichte.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Électrotechnique Montefiore, Bulletin.
Société Belge d'Électriciens, Bulletin.

DUTCH.

Koninklijk Institut van Ingenieurs, Tijdschrift.
Koninklijke Akademie van Wetenschappen, Amsterdam, Proceedings.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Seances.
Bureau des Longitudes, Annuaire.
Société des Anciens Élèves des Ecoles Nationales d'Arts et Métiers, Bulletin Technologique.
Société des Ingénieurs Civils, Mémoires.
Société Française de Physique, Bulletin des Séances.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Schiffbautechnische Gesellschaft, Jahrbuch.
Verein Deutscher Ingenieure, Zeitschrift.
Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Elettrotecnica.
Reale Accademia dei Lincei, Atti e Memorie.

JAPANESE.

College of Science, Kyoto, Memoirs.

SWEDISH.

K. Svenska Vetenskaps-Akademien, Arkiv för Matematik, etc.

SWISS.

Schweiz. Elektrotechnischer Verein, Bulletin.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

BRITISH.

A. E. G. Journal.
Cassier's Engineering Magazine.
Central.
Colliery Guardian.
Electrical Engineering.
Electrical Industries.
Electrical Review.
Electrical Times.
Electrician.
Electricity.
Electrics.
Engineer.
Engineering.
Engineering Review.
English Mechanic.
Illuminating Engineer.
Illustrated Official Journal, Patents.
Iron and Coal Trades Review.
Journal of Gas Lighting.
Light Railway and Tramway Journal.
Machinery.
Mechanical Engineer.
Mining Journal.
Nature.
Page's Engineering Weekly.
Philosophical Magazine.
Post Office Electrical Engineers' Journal.
Railway News.
Royal Engineers' Journal.
Tramway and Railway World.
Vulcan.
Wireless World.

COLONIAL.

Australian Mining Standard.
Canadian Machinery.
Electrical News (Toronto).
Power House.

AMERICAN.

American Journal of Science.
American Machinist, European Edition.
Electric Journal.
Electric Railway Journal.
Electrical Review.
Electrical World.
Engineering Magazine.
Engineering News.
General Electric Review.
India Rubber World.
Journal of the Telegraph.
Metallurgical and Chemical Engineering.
Physical Review.
Scientific American.
Telegraph and Telephone Age.
Telephony.
Terrestrial Magnetism and Atmospheric Electricity.

AUSTRIAN.

Elektrotechnik und Maschinenbau.

DANISH.

Teknisk Tidsskrift.

DUTCH.

De Ingenieur.

FRENCH.

Annales des Postes, Télégraphes, et des Téléphones.
Archives des Sciences Physiques et Naturelles.
Électricien.
Houille Blanche.
Industrie Électrique.
Journal de Physique.
Lumière Électrique.
Mois Scientifique et Industriel.
Portefeuille Economique des Machines.
Revue de l'Ingénieur.
Revue Électrique.

GERMAN.

Annalen der Physik.
Annalen der Physik, Beiblätter.
Elektrische Kraftbetriebe und Bahnen.
Elektrotechnische Zeitschrift.
Elektrotechnischer Anzeiger.
Glückauf.
Jahrbuch der drahtlosen Telegraphie.
Jahrbuch der Radioaktivität.
Physikalische Zeitschrift.
Zeitschrift für Elektrochemie.
Zeitschrift für Elektrotechnik und Maschinenbau.
Zeitschrift für Instrumentenkunde
Zeitschrift für Schwachstromtechnik.

ITALIAN.

L'Elettricista.
L'Elettricita.
Giornale del Genio Civile.
Il Nuovo Cimento.
Rivista Tecnica delle Ferrovie Italiane.

SWEDISH.

Svensk Export.

SWISS.

Journal Télégraphique.
Schweizerische Elektrotechnische Zeitschrift.

THE BENEVOLENT FUND OF THE INSTITUTION OF ELECTRICAL ENGINEERS.

INCOME ACCOUNT FOR THE YEAR 1913.

Dr. Expenditure.	£	s.	d.	Receipts. Cr.	£	s.	d.
To Grants	92	0	0	By Balance brought forward from last year	217	10	9
" Postages, Printing, etc.	2	18	0	" Dividends on Investments	153	14	4
" Balance carried forward	439	1	11	" Interest on Deposit	8	19	4
				" Annual Subscriptions	54	0	6
				" Donations of £5 and over	95	9	0
				" Donations under £5	4	6	0
	£533	19	11		£533	19	11

BALANCE SHEET, 31st DECEMBER, 1913.

Dr. Liabilities.	£	s.	d.	Assets. Cr.		£	s.	d.
To Capital	4,642	3	0	By Investments (Capital):—				
" Income	439	1	11	£961 7s. 7d. Cape of Good Hope 3 % Stock		950	0	0
				£593 1s. 7d. New South Wales 3 % Stock		600	0	0
				£420 Great Eastern Railway 4 % Preference Stock		503	18	3
				£600 North Staffordshire Railway 3 % Debenture Stock		551	0	9
				£750 East Indian Railway 3½ % Debenture Stock		737	18	0
				£300 London and North-Western Railway 4 % Guaranteed Stock		333	11	6
				£500 New Zealand 3½ % Stock		486	18	6
				£500 Canada 3½ % Stock		478	16	0
						4,642	3	0
				" Cash (Income):—				
				At Bankers'	£438 8 4			
				Petty Cash	13 7			
						439	1	11
	£5,081	4	11			£5,081	4	11

We have examined the above Accounts with the Receipt Book, Cash Book, Bankers' Pass Book, and Vouchers, also the Bankers' Certificate of Investments, and we find them to be correct.

H. ALABASTER, SIDNEY SHARP } *Honorary Auditors.*

30th March, 1914.

THE INSTITUTION OF ELECTRICAL ENGINEERS.

REVENUE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1913.

Dr. EXPENDITURE.

		£ s. d.	£ s. d.
To MANAGEMENT :—			
Salaries and Wages		3,321 13 6	
National Insurance		13 18 9	
Accountants' Fees		21 0 0	
Printing		474 5 4	
Stationery and Office Requisites		319 18 11	
Addressing Machine Plates		27 17 6	
Postage of Correspondence and Notices		370 3 4	
Telephone		48 2 9	
Travelling Expenses		20 19 8	
Bank Charges		8 2 2	
			4,626 1 11
„ INSTITUTION BUILDING :—			
Ground Rent		2,201 0 0	
Rates and Taxes		1,610 1 4	
Light and Power		57 19 7	
Firing		203 14 0	
Insurance		77 6 6	
Reserve for Repairs		400 0 0	
Report on Condition of Building		15 15 0	
Letting Expenses		174 7 6	
Household Requisites and Cleaning		82 12 3	
			4,822 16 2
„ INTEREST ON MORTGAGES			1,492 6 4
„ FURNITURE AND FITTINGS (Repairs and Renewals)			102 15 6
„ MODEL GENERAL CONDITIONS :—			
Printing			6 1 4
„ JOURNAL :—			
Printing		1,732 18 5	
Postage		717 16 4	
Wrappers		35 3 0	
Advertising		33 9 8	
		2,519 7 5	
Less Receipts—			
Sales	£464 13 3		
Advertisements	194 0 0		
		658 13 3	
			1,860 14 2
Carried Forward			£12,910 15 5

INCOME. **Cr.**

	£ s. d.	£ s. d.
By SUBSCRIPTIONS		16,081 14 10
„ ENTRANCE FEES		1,354 4 6
„ LIFE COMPOSITIONS		86 6 0
„ BUILDING FUND :—		
Donations and Subscriptions	56 16 0	
Surplus from Vellum Diplomas	55 13 0	
		112 9 0
„ DIVIDENDS ON INVESTMENTS		230 11 7
„ INTEREST		66 2 4
„ WIRING RULES		17 8 9
„ INSTITUTION BUILDING :—		
Rent from Tenants	1,692 12 6	
Less Structural Alterations for Tenants	141 8 5	
		1,551 4 1
„ TOTHILL STREET PROPERTY :—		
Rent from Tenants	643 2 0	
Less Ground Rent, Rates, Taxes, etc.	341 2 5	
		301 19 7
Carried Forward		£19,802 0 8

REVENUE ACCOUNT—*continued.*

Dr. EXPENDITURE—*continued.*

		£ s. d.	£ s. d.
Brought Forward			12,910 15 5
To Science Abstracts :—			
Salaries, Abstracting, Printing, Postage, etc. ...		1,766 7 0	
Less Subscriptions, Sales, and Advertisements ...		1,383 5 11	
			383 1 1
„ Meetings :—			
Advance Proofs		86 19 6	
Reporting		51 9 0	
Honorarium to Kelvin Lecturer		25 0 0	
Refreshments, Assistance, etc.		88 4 9	
			251 13 3
„ Local Sections :—			
Money Grants		811 17 8	
Travelling Expenses		298 4 11	
			1,110 2 7
„ Premiums			142 5 2
„ British Electrotechnical Committee			180 18 3
„ Research Committee			23 10 2
„ Conversazione			237 2 3
„ Annual Dinner			44 18 10
„ Legal Expenses			14 11 8
„ Miscellaneous Expenses			111 1 6
			15,410 0 2
„ Amounts Transferred to :—			
Life Compositions Fund (*per contra*)		86 6 0	
Building Fund (Obligatory repayment to Economic Life Assurance Society) :—			
Donations, Subscriptions, etc. (*per contra*)	£112 9 0		
Contribution out of Revenue... ...	568 2 3		
		680 11 3	
Sinking Fund (Premium for Redemption of Cost of Building and Lease)		277 12 2	
General Fund :—			
Expenditure on—			
Books and Binding for Library		152 2 11	
Furniture and Fittings		327 1 0	
Experimental Apparatus		35 14 11	
Balance, being unexpended Revenue for the year 1913		2,832 12 3	
			4,392 0 6
			£19,802 0 8

INCOME—*continued.* **Cr.**

	£ s. d.
Brought Forward	19,802 0 8
	£19,802 0 8

BALANCE SHEET, 31ST DECEMBER, 1913.

Dr. LIABILITIES.

	£ s. d.	£ s. d.
To BUILDING FUND :—		
Balance at 1st January, 1913	41,815 3 8	
Donations, Subscriptions, etc.	112 9 0	
Contribution out of Revenue	568 2 3	
		42,495 14 11
,, ECONOMIC LIFE ASSURANCE SOCIETY :—		
On Mortgage of Institution Building (1909) ...	26,000 0 0	
Since repaid	2,558 13 1	
	23,441 6 11	
On Mortgage of Tothill Street Buildings and Site (1910)	11,500 0 0	
		34,941 6 11
,, LIFE COMPOSITIONS FUND :—		
Balance at 1st January, 1913	5,474 3 0	
Received in 1913	86 6 0	
	5,560 9 0	
Less Life Compositions of Deceased Members transferred to General Fund	53 10 0	
		5,506 19 0
,, KELVIN LECTURE FUND		862 10 10
,, TRUST FUNDS CAPITAL ACCOUNTS :—		
Salomons Scholarship	2,126 19 3	
David Hughes Scholarship	2,000 0 0	
Wilde Benevolent Fund	1,846 4 6	
		5,973 3 9
,, TRUST FUNDS INCOME ACCOUNTS (Balances unexpended) :—		
Salomons Scholarship	23 16 4	
David Hughes Scholarship	31 15 6	
Wilde Benevolent Fund	304 6 11	
		359 18 9
,, FOREIGN VISIT FUND		92 14 2
,, SUNDRY CREDITORS		3,203 8 2
,, SUBSCRIPTIONS RECEIVED IN ADVANCE		210 16 7
Carried Forward		93,646 13 1

ASSETS. **Cr.**

	£ s. d.	£ s. d.
By INSTITUTION BUILDING AND LEASE :—		
Cost	73,028 6 10	
Less Reserve for Depreciation, being Sinking Fund Premiums paid	1,293 15 4	
		71,734 11 6
,, TOTHILL STREET BUILDINGS AND SITE (at cost)		19,260 17 1
,, SINKING FUND (Premiums paid for Redemption of Cost of Building and Lease)		1,293 15 4
,, LIFE COMPOSITIONS INVESTMENTS (at cost) :—		
£2,600 Natal Zululand Railways 3% Debentures	2,270 12 0	
£1,500 Lancashire and Yorkshire Railway 4% Preference Stock	1,513 10 4	
£2,000 Assam Bengal Railways 3% Stock ...	1,548 0 6	
		5,332 2 10
,, KELVIN LECTURE FUND INVESTMENT (at cost) :—		
£1,000 2½% Consolidated Stock		862 10 10
,, TRUST FUNDS INVESTMENTS (at cost) :—		
Salomons Scholarship :—		
£1,500 New South Wales 3½% Stock	1,556 5 9	
£500 Cape of Good Hope 3½% Stock	570 13 6	
		2,126 19 3
David Hughes Scholarship :—		
£2,045 Staines Reservoirs 3% Guaranteed Debenture Stock		1,998 15 0
Wilde Benevolent Fund :—		
£875 Great Eastern Railway Metropolitan 5% Guaranteed Stock	1,493 16 3	
£215 North Eastern Railway 4% Guaranteed Stock	250 19 9	
£100 London County 3½% Stock	101 8 6	
		1,846 4 6
,, LIBRARY :—		
As per last Balance Sheet	1,446 16 6	
Additions in 1913	152 2 11	
	1,598 19 5	
Less Depreciation (10%)	159 17 11	
		1,439 1 6
Carried Forward		105,894 17 10

BALANCE SHEET—*continued.*

Dr. LIABILITIES—*continued.*

	£ s. d.	£ s. d.	£ s. d.
Brought Forward			93,646 13 1
To Reserve for Repairs :			
Amount set aside in 1913		400 0 0	
Less Expenditure on Repairs in 1913		216 16 10	
			183 3 2
,, General Fund :—			
Balance at 1st January, 1913		17,065 12 4	
Life Compositions of Deceased Members ...		53 10 0	
Expenditure in 1913 on—			
Books and Binding for Library		152 2 11	
Furniture and Fittings		327 1 0	
Experimental Apparatus		35 14 11	
Unexpended Revenue for 1913		2,832 12 3	
		20,466 13 5	
Less Depreciation (*per contra*) :			
Library	£159 17 11		
Furniture, Fittings, and Apparatus	135 10 5		
		295 8 4	
			20,171 5 1
			£114,001 1 4

ROBERT HAMMOND,
Honorary Treasurer.
P. F. ROWELL,
Secretary.

ASSETS—*continued.* **Cr.**

	£ s. d.	£ s. d.	£ s. d.
Brought Forward			105,894 17 10
By Furniture, Fittings, and Apparatus :—			
As per last Balance Sheet		2,347 12 4	
Additions in 1913 :—			
Furniture and Fittings	£327 1 0		
Experimental Apparatus	35 14 11		
		362 15 11	
		2,710 8 3	
Less Depreciation (5 %)		135 10 5	
			2,574 17 10
,, Sundry Debtors			1,282 13 8
,, Rates Paid in Advance...		41 13 3	
,, Insurance Premiums Paid in Advance		154 10 11	
			196 4 2
,, General Fund Investments :—			
£750 Western Australia 4 % Stock		730 8 3	
£750 Union of South Africa 4 % Stock		742 12 0	
£750 Madras and Southern Mahratta Railway 4 % Debenture Stock		738 15 6	
£35 East Indian Railway "B" Annuity		791 5 4	
			3,003 1 1
,, Cash :			
At Institution Bankers'...		708 17 8	
Petty Cash		36 2 2	
P.O. Savings Bank (Wilde Benevolent Trust Fund)		304 6 11	
			1,049 6 9
			£114,001 1 4

We beg to report that we have audited the Balance Sheet of the Institution of Electrical Engineers, dated 31st December, 1913, and above set forth, together with the annexed Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct, and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of our information and the explanations given to us and as shown by the books of the Institution.

ALLEN, ATTFIELD AND CO.,
Chartered Accountants,

147, Leadenhall Street, E.C.

25th March, 1914.

H. ALABASTER
SIDNEY SHARP } *Honorary Auditors.*

SALOMONS SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1913	75 0 0	By Balance (as per last Account)	28 16 4
„ Balance carried to Balance Sheet	23 16 4	„ Dividends received in 1913	70 0 0
	£98 16 4		£98 16 4

DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1913...	50 0 0	By Balance (as per last Account)	20 8 6
„ Balance carried to Balance Sheet	31 15 6	„ Dividends received in 1913	61 7 0
	£81 15 6		£81 15 6

WILDE BENEVOLENT TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Balance carried to Balance Sheet	304 6 11	By Balance (as per last Account)	242 4 3
		„ Dividends received in 1913	55 17 0
		„ Interest do do.	6 5 8
	£304 6 11		£304 6 11

DISCUSSION ON

"SUGGESTED METHODS OF IMPROVING THE TELEPHONE SERVICE."*

NEWCASTLE LOCAL SECTION, 9TH FEBRUARY, 1914.

Mr. Elliott. Mr. J. R. M. ELLIOTT: With regard to the difficulties caused by subscribers themselves, it is unfortunately too true that difficulties of this nature are constantly arising. This is especially the case at private branch exchanges. After all, however, it is the duty of telephone engineers to design apparatus for use at the subscriber's end of the line to be as fool-proof as possible. Under the heading of "Automatic disconnection on manual switchboards" the author's suggestions are very ingenious, and although they may have advantages there are on the other hand certain disadvantages. For instance, if the receiver hook be inadvertently touched by the subscriber during conversation the connection will be automatically severed. This would lead to frequent complaints. It may be urged that this would take place in the case of an automatic system. Quite so, but in manual systems one of the advantages is that the operator has the power of discrimination and momentary signals of this kind would be ignored. Referring to the suggestions for the cord circuits, the proposals involve two additional relays per position. Would this not introduce a number of microphonic contacts? The question of accommodation in many of the smaller exchanges is a serious factor which must be taken into consideration, and as the space available is often so cramped and limited it would be a difficult matter in some cases to find room for additional relays. The author says that it is not essential to withdraw the plugs immediately; but if the operators were allowed to depart from this practice would not the result be a tendency towards slackness in operating? With the present system of lamp signalling at exchanges the fundamental basis on which the system has been built depends upon a lamp flash for every function to be performed; any departure from this practice would cause confusion in the minds of the operators. In the author's proposal it would be possible to have a maximum of 17 lamps glowing on the keyboard in front of the operator. Would not this throw a glare upon the bank of calling lamps? There is also the cost of the wear and tear of these lamps. The supervisors when walking round behind the operators would have a difficulty in noting the number of lamps glowing on the horizontal keyboard. Presumably the author does not intend to alter the position of these lamps from the horizontal to the vertical plane. Is it intended that the pilot lamp should be retained? The author has made suggestions for improving the service by modifications of the apparatus; but it may be explained that the Department in addition to spending large sums of money on apparatus equipment is improving the service by increasing the number of junctions and trunk lines throughout the country. It may be of interest when I state that in this district alone the sum of something like £40,000 is at the present time being expended in laying cables for junction lines between Newcastle, North Shields, South Shields, and Sunderland, and that a further sum of about £30,000 is being expended on the construction of new trunk lines in the district. Mr. Elliott.

Mr. Batchelor. Mr. W. M. BATCHELOR: I think the author's suggestions are fundamentally wrong in principle. No doubt he is acquainted with the No. 9 common battery switchboard of the Western Electric Company. This board was designed to provide in a cheap form a central battery service for small exchanges having accommodation for about 800 subscribers' direct lines. The principle of negative signalling was adopted, but although the board is of a fairly modern type it is being discarded wherever it has been installed, mainly owing to the inadequacy of negative signalling. It is essential in telephone practice to have a definite signal for each requirement. A glowing lamp indicates to the operator that something must receive attention, and the absence of a signal means that everything is clear. The author's proposal is to revert to an obsolete method of signalling. Again, one of the most important features of the present system is the definite supervisory signal from each side of the cord. In the author's proposal for private branch exchange boards the clearing signal is being reduced to one in place of the double clearance now obtained. In this, in effect, he appears to be giving the equivalent of the clearing signal obtained on the old magneto boards. I may say that other methods of dealing with this subject have been proposed by two officers of the Engineer-in-Chief's Department of the Post Office, and the system that they have designed is now being investigated by the Department. In their system it is not proposed to abandon positive signalling, and in this feature it would appear to have a marked advantage over the author's system. At the bottom of page 325 the author suggests that the "B" operators might leave the junction circuits connected until they were required for another connection. Present practice, however, prohibits this, because with keyless junctions if the "A" operator were to connect to the junction before the "B" operator had disconnected from the line last in use, a false call would be sent out.

Mr. Baldwin. Mr. F. G. C. BALDWIN: The title of the paper implies that the methods which the author suggests should be adopted may be applied in improving the service generally. This is not so, however. The paper deals with central battery systems only, and takes no account of the numerous large magneto systems that are in existence at the present day and to which the alterations described cannot be applied. The central battery system ever since its introduction has been subject to constant improvements, most, if not all, of which have tended to make its operation increasingly automatic, and the author's suggestions are a further step in this direction. If adopted, the methods suggested would constitute a very drastic departure from the standard central battery practice that has been generally adopted not only in this country but also abroad, and it seems very probable that any advantages which might be gained would be more than counterbalanced

* Paper by Mr. W. Aitken (see p. 320).

Mr. Baldwin.

by the disadvantages that would accrue from the introduction of the methods put forward in the paper. From the operating standpoint the adoption of a negative clearing signal seems particularly undesirable. At present the operator has one idea in mind, viz. to keep the signal lamps out; the combination of positive calling and negative clearing signals is certain to be at least disconcerting, and would probably tend towards confusion and error. It seems to me that the author underestimates the extent and cost of the alterations which he suggests should be made. In addition to the fitting of the additional relays and the extra springs to the speaking key, other alterations would practically involve the complete re-wiring of the cord circuits. It is by no means conclusive that automatic disconnection on a manual system is desirable. One of the principles on which operators now work is that they must restore their cords as quickly as possible. This is not altogether with the idea of effecting a quick clear, but also in order that a maximum number of cords may be available. If the operator is aware that the withdrawal of the plug is not absolutely necessary in order to open the subscriber's circuit to further calls, the result will probably be that the cords will not be restored, and discrimination between cords in use and out of use will then be difficult and lead indirectly to an increase in the time of answering, which at present is satisfactorily low. The author has referred, although briefly, to incorrect operating on the part of the subscriber; now the subscriber or his staff is himself frequently responsible for much of the trouble that he experiences, but he usually places the blame without discrimination upon the operators. The average subscriber is not at all anxious, or sometimes even willing, to co-operate in endeavouring to secure a generally efficient telephone service, and he either cannot or will not understand that his indifferent treatment of the telephone causes trouble to his fellow-subscribers. As an example, only as recently as a fortnight ago a subscriber complained to me that the operator declined to accept a call in the "name" of a subscriber and he considered it a hardship that he should be compelled to give the number. The adoption of such unreasonable attitudes by subscribers operates adversely on the telephone service. Then as regards the alleged frequent reply, "Engaged." The average subscriber cares very little or nothing for his incoming traffic. His outgoing calls are his chief consideration. Numerous subscribers' lines are so heavily worked that it is almost an exceptional thing to find their telephones disengaged, and yet when representations are made to them that the present line or lines cannot cope with the traffic they usually decline to have additional lines, and so their customers or clients go elsewhere to do business. The suggestions made in the paper would, if adopted, seem rather to increase the risk of "cut off" than diminish it. In addition to the possibility of the operator restoring a wrong pair of cords, the automatic disconnection advocated in the paper will absolutely sever a connection should a momentary "clear" be given either accidentally by the calling subscriber or by an intermittent defect on his line or apparatus. Such a "clear" would at present be disregarded by the operator.

Mr. Shaw.

Mr. HERBERT SHAW: I think the chief reason for the existing dissatisfaction arises from two primary facts. The first is that the National Telephone Company, knowing that its lease would terminate on the 31st December, 1912, naturally intended to make no further capital expenditure than was necessary. The second is that the Post Office never realized that the expiry of the lease was drawing near, and so it took no trouble to prepare for the transfer, especially in regard to the expenditure necessary for new work. The service which has been recently experienced is worse than that under the National Telephone Company, at least in the opinion of many business men. Had Parliament known as much about the telephone service in 1905 as is known now, I am sure that the country would never have agreed to the transfer. In regard to details, I agree that the principle of the measured-rate service is sound. Although I admit that any ordinary flat rate may result in a line being overloaded, I also think that the measured-rate service is exorbitant in price and too limited in regard to the number of permissible calls. I infer this from the experience of other countries, and if the same method of calculation is retained I am convinced that dissatisfaction will be expressed throughout the country. I consider that each subscriber should have a meter on his instrument and that the necessary arrangements should not be solely in the hands of the charging authority. I also think that until some recording meter is so installed the measured rate should not have been introduced. The authorities seem to think that 4,000 calls per annum is sufficient for one line, and that with a greater number it becomes overloaded, although it amounts to only 12 calls a day. I cannot agree with this view. The National Telephone Company considered that 6,000 calls per annum would be a reasonable number for one line. The present charge is too high and the number of calls allowed is too small. Another trouble locally is that there are not sufficient junction wires connecting the City Exchange and the old National Telephone Company's Exchange in Pilgrim Street. I am very glad to learn that at the present moment a further number of extra cables are being installed. I think it will be agreed that it is unsatisfactory to have two separate exchanges; when the new building is erected it is to be hoped that a better service will be available. I do not wholly blame the Post Office authorities: subscribers are very often at fault. An assistant may be asked to ring up another subscriber and, having awaited a reply, informs his principal, who finds that the subscriber required is not there. This is a great nuisance and is responsible for the waste of much time. Greater expedition should also be used in handling calls. Another trouble is that a large number of wires are carried overhead, and naturally some of them are blown down in stormy weather as well as being easily put out of order by other causes. I venture to think, however, that a real and decided improvement has taken place recently and that ultimately many of the evils will be eliminated, as they indeed have been during the last few months.

Mr. Kitchen.

Mr. H. KITCHEN: In Fig. 1 it appears to me that the lamp signals are confusing. Lamp L_2 glows continuously during the period that the cord circuit is in use; whereas lamp L glows until the called subscriber answers, but it does not glow if the calling subscriber clears previously to the called subscriber. Both lamps glow if the called subscriber clears first. I am afraid this cannot be called an improvement on the present double supervisory signalling. On page 322 the author says in justification of negative

tchen. signalling that the number of lamps glowing is a valuable indication of the operator's load. It is scarcely necessary to point out that an operator's load is not in proportion to the number of cords in use at any one time. The automatic registration of calls described on page 323 appears to be a somewhat delicate arrangement. If I read the diagram correctly, the passage of the recording impulse is made through the flexible contacts of relay R. Connections with two arms are made for a very short period, and as they must also be made simultaneously I shall be surprised if considerable trouble is not experienced in maintaining them in working order. The junction working shown in Fig. 3 has a decided drawback, insomuch as the "B" operator is unable to test for the engaged signal until the "A" operator has connected her subscriber. This appears to be a retrograde step, and would considerably retard order-wire junction working which is at present the most satisfactory part of central battery telephony. I am afraid that the suggested tone test cannot be regarded as an entirely satisfactory device.

kins. Mr. F. W. GASKINS: I should like to add a few remarks in connection with complaints Nos. 1 and 6, which have so far not been touched upon and which cannot in my opinion be cured by the addition of relays or extra springs in any part of the circuit. The author admits that the complaints are not very specific, and those who are engaged in telephone work are in a position to say that a large proportion of such complaints are without any foundation in fact, whilst many can be—and are—traced to the delinquencies of subscribers themselves. If we take the whole of the telephone subscribers in this country and ascertain the total number of legitimate complaints in hand at any one time, it will probably be found that the ratio is only a fraction of 1 per cent. I am convinced that many of the complaints made by subscribers would never be made at all if they were better acquainted with the conditions inside some of the larger exchanges during the busy hours of the day. There is no doubt, however, that on the completion of the work which is now in progress in almost every large town in the country, such as the installation and extension of internal and external plant of the most up-to-date type, very many of the complaints of the nature of those under discussion will disappear. These schemes are being expedited, since the State telephone authorities are quite as anxious to provide —as are the public at large to obtain—a perfect telephone service. With regard to complaint No. 6, I hold no brief for the operators, but as a member of the staff of the authority responsible for the telephone service, I cannot let the statements made pass unchallenged. I must say that I think the author's remarks with reference to the operating staff are somewhat harsh and perhaps rather stronger than the facts will actually justify. To support this view I would point out two outstanding features which should certainly ensure a service of no less efficiency than was provided before the transfer. In the first place the traffic staff is controlled by practically the same officials as before, and secondly the transferred operating staff especially have been most generously treated in the matter of remuneration, etc., by the Post Office. The author's object is most laudable, but to my mind there appear to be some grounds for doubt as to whether the modification of existing plant by the method suggested would prove such an unmixed blessing as the paper might afford reason to expect. It is possible to conceive that the additional mechanism proposed to be used and the suggested methods of lamp working might be the cause of an amount of trouble outweighing any improvements likely to follow the adoption of the author's proposals. It would be interesting to have information on this point, and I should like to ask the author whether he would be prepared to take the responsibility of the installation of the proposed extra apparatus, and afterwards of maintaining an exchange, concurrently giving an undertaking that the total number of complaints would be less, or at least no more numerous, than before, if he were to adopt the improvements suggested in the paper. Mr. Gaskins.

Mr. W. G. GUNS: Are the improvements suggested in the paper to be justified by the fact that the staff can be reduced; or does the author suggest that as the Government is the paymaster the question of the extra cost is immaterial? Mr. Guns.

Mr. G. E. GILPIN: I do not quite see how satisfactory speaking-circuit connections could be maintained through four relay contacts as is shown in Fig. 1, for, as has already been mentioned by Mr. Elliott, and also as a result of experience, it is believed that such arrangements usually give rise to working difficulties. In regard to the plugs and cords being left in the answering and multiple jacks after a clearing signal had been given, say on position No. 1, it does not necessarily follow that the subscriber answered on No. 1 position would be the first to originate a second call—as this may be made by the subscriber into whose line the plug in the multiple was inserted—when the calling indication for the latter might be upon, say, position No. 3. At this point the second subscriber could be switched through to a third party, and then if after a few moments the first subscriber called, the operator on No. 1 position would push over the speaking key of the pegs and cords already left in the jacks and so cause a triple connection to be made. Mr. Gilpin.

Mr. W. BAXTER: As a telephone subscriber, I should like to say that although the service is not by any means perfect, it is very good on the whole. I concur with the author that much depends upon the competence of the subscriber's operating staff. Some years ago I had experience of a private branch exchange with about 8 or 10 circuits, and as the newest office boy had always to attend to this exchange, complaints were very numerous. Eventually a permanent operator was employed and trouble became almost a thing of the past. Mr. Baxter.

Mr. W. AITKEN (*in reply*): With reference to Mr. Elliott's remarks about the possibility of premature disconnection by momentarily touching the switch circuit, I may say that this applies also to the full automatic system. On the proposed system the calling subscriber on replacing his receiver will restore everything to the normal. On the common battery system if anybody accidentally lifts the receiver, say when cleaning the instrument, a call is given. The sooner the subscribers are taught that this movement of the switch hook will cause automatic disconnection the better, since full automatic systems will eventually be adopted. Mr. Aitken.

With reference to the space necessary, and generally as to the cost of the modifications, I think that this cost is practically negligible compared with the total cost of a

Mr. Aitken. telephone exchange. The cost of an exchange where 50 operators are required may amount to as much as £6 per line, whereas the cost of installing these modifications is probably only about 5s. per line. In modern common battery exchanges special racks are provided to carry relays, and I think that there would be no difficulty in finding room for 34 relays per position. I also do not quite follow Mr. Elliott's point with regard to the number of contacts and relays; in automatic systems more and more relay contacts are being introduced, and they have stood the test of very severe service universally.

Mr. Elliott also remarked about the glare. Should this be found inconvenient the light can easily be subdued by using coloured lamp caps. In regard to supervisory lamps on the horizontal board, Mr. Elliott asks if the pilot lamp would be retained. It is not usual to have a pilot lamp for the supervisory signals, and I have said that the multiple panels remain unaltered. Speaking generally, it may be said that at present lamps are provided on common battery systems to tell the operators to carry out certain functions. I propose to disconnect the line without any signal and to provide signals to protect the called subscribers only. If no lamp is glowing in front of a cord, the cord is idle and there is therefore no need to instruct the operator to do anything.

Mr. Batchelor says that negative signalling is fundamentally wrong, but I do not propose in my system to give any signal at all, as the disconnection would have already been carried out. In a common battery system two supervisory lamps are necessary to inform the operator that the plugs must be withdrawn to disconnect the circuit, but if the disconnection is beyond the control of the operator, why give her such signals? All that is necessary is to tell the operator that the plugs are available for other uses. In the No. 9 common battery switchboard referred to, there were no answering jacks and the line signals were not directly associated with the lines. I believe that these are now being replaced as the small capacity for which they were designed is reached.

Mr. Batchelor also referred to the automatic system proposed by two Post Office engineers. I only know that there is such a system, and that their patent was applied for some eight months later than mine. I have heard that they are obtaining similar results in a different way. With reference to false calls on junctions, once the receiver has been replaced the circuit will be automatically disconnected at both ends.

Mr. Baldwin said that the system is not readily applicable to magneto systems. I believe that it could be applied, but that it would not be worth the trouble. The magneto system for large exchanges is obsolete, and the sooner such apparatus is replaced the better it will be for the service. Mr. Baldwin thinks that the efficiency may be reduced by the introduction of this system. At present if an attempt is made on a manually-operated system to get say a dozen consecutive calls through, it will be found to work exceedingly badly. On an automatic system I have no hesitation in saying that the calls will be effected in one-third of the time. This speaker seems to suggest that operators would leave the plugs in, but the supervisor will of course see that this is not done. I advocate only that the plugs might remain in rather than a calling subscriber be kept waiting. With my system there is nothing to be gained by withdrawing the plugs instantly, and the Mr. Aitken. operator will answer the calls without any hesitation, knowing that the cords are available for use at any moment.

Mr. Shaw mentioned a point on which I should like to comment, namely that assistants, usually office boys, are deputed to make calls for a subscriber. I think there are two sides to that question. It is most annoying to hear a boy at the other end of a telephone line say, "Is that So-and-so?" and, on receiving the reply "Yes," remark, "Wait a minute," then going away without giving any idea as to who wishes to speak or what is wanted. The service would be very greatly improved if subscribers would initiate their own calls instead of deputing this to boys.

Mr. Kitchen refers to the operation of the meter. I do not anticipate difficulty in obtaining a suitable relay.

Mr. Gaskins said that my remarks in regard to the operators are harsh. I had no intention of being so. He also asked whether I should be prepared to install my system and guarantee that there would be no complaints; but that is not my business.

In reply to Mr. Guns, I put the paper forward as being suggestive, and I think the improvement claimed and the simple way of attaining the results merit very serious consideration. The question of reducing the staff, or rather giving each operator a greater number of lines, is not of primary importance, but rather the improvement of the efficiency of the service.

As to the triple connection referred to by Mr. Gilpin, I do not see why this should be the case. It infers that the plugs are not to be withdrawn in a reasonable time. Should the peculiar combination arise, the operator would also be in circuit and detect the trouble. There is no microphonic action in good relay contacts.

To sum up: I think that too much importance is being placed by my critics on two-lamp supervision. In an ordinary common-battery system there is much in its favour, but I do not agree that even there it is essential as a disconnecting signal. One lamp would be equally efficient if controlled by the caller or either subscriber, as was the case in the "ring-through" system. Double supervision is not effective on common-battery systems when a call is through to a trunk exchange, neither is it efficiently used on "A" positions when connection is made with a junction to a magneto exchange. One signal is also reckoned as sufficient at a "B" position. Double supervision was not invented because it was desirable in itself; it was simply a by-product. The cord circuit had to be divided by repeaters and similar apparatus so as to supply current to the microphone of each line connected, and two signals necessarily followed. They proved useful because they indicated the condition of each side of the circuit.

On automatic systems introduced by the Post Office the disconnect control is placed in the hands of the calling party, proper means being provided to prevent the called party being "hung up." I provide an exactly similar arrangement.

The lamps associated with the answering plug may be coloured red, and they indicate to the operator and the supervisor at any time the number of "live" connections. The calling cord lamps are white as at present, and indicate by glowing that the called party is being "hung up." They also act as supervisory lamps to indicate when the

Mr. Aitken. called party answers. The fact that no lamps are glowing indicates idle cords, as at present—whether the plugs are in their sockets or in jacks. Where is the negative signalling? No signal is necessary to disconnect and none is provided. The operator, when convenient, returns idle plugs to the sockets.

The interpretation of the signals is certainly slightly different from the present common-battery methods, but so slight that an operator would learn it in two minutes, and in 10 minutes would appreciate all the advantages accruing from the lessened responsibility and ease of operating. Knowing that the disconnection was under the control of the subscribers, that the lines immediately thereafter test idle, and that a lamp glowing (otherwise than as mentioned above) is a new call for a connection, I believe that the operators' work would be much less worrying and exacting. The advantages from the subscribers' point of view are :—instant release from a connection when the receiver is replaced, repeat calls instantly answered, the reply "Line engaged" reduced to the minimum, together with a number of more indirect advantages.

DISCUSSION ON "ELECTRIC BATTERY VEHICLES."*

Scottish Local Section, 24th March, 1914.

Mr. Page. Mr. A. Page : It has no doubt occurred to many of us to enquire why this apparently new interest in the development of electrically-propelled vehicles has arisen. It would appear to be chiefly due to the energy of the American manufacturing firms and to the efforts of the electricity supply companies in cities like Chicago and New York in obtaining new business. The matter seems to have been taken up in this country during the past two years mainly because of the desire of central-station engineers for more load of the off-peak class. The increasing cost of petrol and the smell and noise of petrol-driven vehicles have also given an impetus to the movement. The evolution of the Edison nickel-iron-potash cell has latterly afforded those engineers who did not believe in any form of lead battery a feeling of returning confidence in the possibilities of the electric vehicle. Those interested in public health are also keenly alive to the possibilities of electricity for the propulsion of vehicles. It is agreed by all who have considered the question that if the smell of petrol and the soiling of our streets due to horse traction could be eliminated, a considerable addition would be made to the amenities of passenger traffic in main thoroughfares. There is a popular misconception that a battery-driven vehicle must always run at low speeds. It is quite possible, however, to get high speeds provided that the money is spent on battery equipment and motors of sufficient power. It is well, however, to acknowledge that the higher speeds are the legitimate sphere of the petrol-engine vehicle and should be left to it. The standard speeds now fixed by electric-vehicle manufacturers are the outcome of long tests to ascertain the most economical speeds at which these vehicles should be run. It is claimed that they run at a fairly constant speed —the average of the very high and the very low speeds of the petrol car. The tendency of petrol-car drivers to maintain full speed so long as they can do so with impunity, is at once very costly in tyres and in the wear and tear of working parts, in addition to being quite unnecessary. At present the electric vehicle may be most advantageously used for city work, especially for commercial purposes. Its advantages are the ease of manipulation, absence of noise and smell, low maintenance cost (especially for tyre renewals), absence of reciprocating motion, low running cost, high starting torque, rapid acceleration, and easy hill-climbing. The disadvantages are the limited radius of operation and high first cost. Where electric vehicles are confined to the class of work for which they are peculiarly adapted these objections are unimportant. In the electric vehicle there are no cylinders, gear box, carburettors, ignition, magneto, or clutch to cause trouble. The lead-sulphuric acid battery, which 10 years ago was the cause of the failure of several well-meant efforts to popularize the electric vehicle, has been very greatly improved within the last five years. The question of whether a lead battery or an Edison battery should be employed resolves itself into what the buyer is prepared to pay in the first instance. A first-class lead battery can be obtained at about one-third of the cost of the nickel type. The lead battery with careful attention will run a vehicle 10,000 miles on good roads. The Edison battery, on the other hand, is guaranteed for four years, and no reservation is made regarding mileage. It is possible in four years to run a vehicle 60,000 miles. On the whole I think that the balance of argument is in favour of the Edison battery, although I know that in America many people say they prefer to have a new lead battery every year. Recent improvements in lead cells are the reduction in weight and the increased strength of the plates, the use of separators between plates, and generally the production of a sound, workmanlike article with the cell totally enclosed and no chance of leakage of the electrolyte.

The Edison cell has positive plates of nickel hydrate and negative plates of iron oxide. The electrolyte is an alkali consisting of a 20 per cent solution of potassium hydrate plus a small percentage of lithium hydrate. The positive plates in the A.4 size are made up of 15 double rows of spirally-wound steel perforated tubes. The spirals are held in position by 8 steel rings threaded on to the spiral tubes, the spirals having double-lapped seams. The diameter of each spiral is 0·25 in. The nickel hydrate or active material fills the steel tube in a series of thin layers, between which is placed metallic nickel. This latter is used as a conducting substance, so as to give as many paths as possible for current passing through the tube.

* See p. 493.

Mr. Page. The 30 tubes are held vertically by a steel supporting frame. The negative plate consists of three rows of thin nickel-plated steel pockets finely perforated. Each pocket, after being filled with iron oxide, is subjected to high pressure, so that all the pockets become practically a part of the electro-plated supporting grid. Each cell of the size shown contains four positive and five negative plates. The plates of each group are bolted together and connected to the terminals in a sound mechanical manner, the terminals being tapered at the part outside the steel boxes. Ebonite is used for insulation purposes between adjacent plates, and also between the plates and the case. The sides of the boxes, which are electro-plated, are corrugated for strength. The terminal rods are brought out through stuffing boxes and glands made of ebonite or compressed paper, which also serve as insulators. The various parts are all fitted so that when the cell is assembled it can be shaken violently without suffering harm. It is also watertight, there being mounted on the cover a valve which acts as a vent to allow gas to escape, but which prevents anything entering from the outside. The valve also acts as a separator, freeing the escaping gas of the entrained electrolyte and returning it to the solution. The filling of the cell with fresh electrolyte or distilled water is effected by means of an opening at the top provided with a special filler. This opening is closed by a gas-tight spring cap. The cells give off no destructive and unpleasant fumes, which are a bad feature of the lead-type cell. The Edison cell has double the capacity of the lead cell for the same weight, although the overall dimensions are about the same in each case, and it can be left without harm for long periods in a discharged state. The size of cell that we use, namely. 150 ampere-hour capacity, costs 72s. each. The voltage of the Edison cell, when fully charged, is 1·8, as against 2·5 for lead cells. To avoid explosion a naked light must not be allowed near the battery while it is being charged. The electrolyte is neutral as far as action on the outer steel case is concerned.

A good feature of the electric vehicle is that owing to the presence of a battery motors can be installed on trucks for driving pumps or cranes. In other words, the electric drive has the same range of flexibility in a vehicle which it has elsewhere. It is difficult at present to secure reliable information regarding the cost of running electric vehicles. Judging from the number of people who call to discuss the question at the Glasgow Corporation Electricity Department offices, there is no doubt that very little encouragement is needed to ensure a large fleet of electric vehicles being in use in Glasgow in the near future.

It may be of interest to describe the electric van belonging to the Glasgow Corporation Electricity Department: The vehicle is of the light van type to carry 2,000 lb., and the chassis was built by the Anderson Electric Car Company of Detroit. The body was built in this country to our requirements. There are no changing or reversing gears, the former being accomplished by cutting resistance "in" or "out" in conjunction with a series-parallel arrangement of field, the latter by a reversing switch. A tray fixed to the chassis below the floor level carries the cells. This tray is large enough to take 60 cells of the Edison A.6 type, having a capacity of 225 ampere-hours, but in this vehicle 60 of the A.4 size of Edison cell having Mr. Page. a capacity of 150 ampere-hours are installed. The motor is four-pole series-wound. The handle for working the controller and the reversing switch is placed at the steering wheel. The controller is of the drum type giving four forward and four reverse speeds. An ampere-hour meter is fixed to the front of the dash-board and registers the input and output of the battery. When charging, owing to the instrument being constructed with a differential shunt, the pointer comes back to zero more slowly than on the discharge, the meter thus automatically allowing for the loss in the battery. Our usual method of working is to charge at the normal rate of 30 amperes during the night for seven hours. This time is, however, often reduced by starting at 50 amperes and working back to 30 amperes as the battery voltage rises. Boosting charges are given at the midday meal hour, charging at the 50-ampere rate, although no harm is done to the battery if the charging rate is increased to four times the normal. The only objection to this method is that the battery does not give the same mileage. The motor drives the differential shaft through a silent tooth chain. Both rear wheels are driven from the differential shaft by roller chains. The motor is geared down 11 6 to 1. There are two foot brakes, one of which acts on the differential shaft and the other on the hub of the rear wheels, the back brake being of the internal expanding type. The weight of the van is 34 cwt., including battery, the weight of which is 7½ cwt. The maximum speed is 10 miles per hour. We chose the A.4 type of cell, which on a good asphalt level road will carry the van 40 miles. Our tests show that the average result to be obtained on Glasgow roads is 33 miles on one charge. The van, empty, as actually tested, will stop and start on a gradient of 1 in 4. The speed up very steep hills is about 3 miles per hour. Solid rubber tyres are fitted on all wheels. The van was purchased in the beginning of March, 1913, since which time the mileage has amounted to 10,200. Table A gives the mileage for four weekly periods up to date, also the number of units per car-mile for each of these periods.

TABLE A.

Glasgow Corporation Electricity Department. One-ton Electric Van—Running Statistics for One Year.

Four Weeks Ending	Units per Mile	Miles run
April 2, 1913	0·65	560
April 30	0·59	813
May 28	0·58	907
June 25	0·54	860
July 23	0·52	949
Aug. 20	0·51	912
Sept. 17	0·53	854
Oct. 15	0·58	775
Nov. 12	0·65	875
Dec. 19	0·65	422*
Jan. 7, 1914	0·66	785
Feb. 4	0·66	957
Mar. 4	0·68	683†

Total mileage ... ... = 10,352.
Average number of units per mile = 0·61.

* Repairs 21 Nov.—4 Dec. † Repairs 17—20 Feb. and 26 Feb.—4 Mar.

Page. It will be noticed that the number of units is less in the spring and summer months than in the winter months. This is undoubtedly due to differences in road conditions. The average number of units per car-mile for the whole period works out at 0·61. It will also be noticed that there have been few repairs. The repairs in March of this year included fitting new tyres to front wheels, new steering rod, new sprockets on the differential, and other small adjustments. In one year we have used one silent tooth chain and three sets of roller chains. From this record we have proved that the upkeep of the van is very much less than what we found by experience to be the case with a petrol-driven vehicle. The workmanship on the chassis is of a very high class. Roller and ball bearings are fitted throughout, the greatest care being taken to get the power of the motor applied to the wheels with the minimum loss. The electric vehicle has displaced two horse vans, and we are getting our work done more economically and in a much smarter manner. It is available for breakdowns and other work throughout 24 hours of the day, and is of great service when a "jointer's squad" is required for emergency work, especially at night, as all the tools and other gear wanted can be taken direct to the breakdown with the men. The chassis cost £560, and the body £45. The running cost depends largely on the use made of the vehicle. To get the best out of it the vehicle must be run as continuously as possible, and for not less than 10,000 miles per annum.

Another point in favour of the development of the electric car is that the price of electricity is steadily falling, whereas the cost of petrol is rapidly and continuously rising. In fact, the price of petrol has gone up 75 per cent during the last two years. In regard to touring by electric vehicles, this will involve the erection of charging stations at proper intervals throughout the country. I am afraid it will be a considerable time before such a development takes place. All the parts of the vehicle will have to be standardized so as to give the minimum of trouble to the electric vehicle user.

Craig. Mr. J. H. CRAIG: The table given by Mr. Page, showing the cost of running the Edison-battery-equipped vehicle belonging to the Glasgow Electricity Department corroborates other results obtained both in London and in various American cities with similar types of vehicles. Such results undoubtedly justify us in holding that there is a most promising field open to the electric vehicle; but although we can prove its running costs to be less than those of its petrol-driven rival, we cannot expect to convert the purchasing public without a great deal of hard and uphill work. The petrol vehicle has been in the field for some time and is well entrenched in its position, not only for pleasure but also for commercial purposes. When I say this I do not forget that there were storage-battery-driven vehicles years before the petrol vehicle was brought into use. The battery of those days, however, was very different from the improved lead, or the perfected Edison nickel-steel battery of to-day. It was in August, 1892, that I equipped what was, I believe, the first electric vehicle (excepting tramcars) in America. This vehicle was a four-wheeled dog-cart, and was built in Brookline (Massachusetts) to drawings brought from London by a wealthy Boston man who was interested in the subject of mechanical road traction. The motor also came from London and was a 4-h.p. "Immisch" machine. This vehicle was equipped with E.P.S. pasted lead cells in ebonite tanks with lids. With the battery and a load of four people the vehicle weighed about 5,000 lb., and having iron tyres and not being well sprung it moved most ponderously. The acceleration was small, but on the level and with a good surface a speed of about 7 miles per hour could be reached. We now have batteries which are absolutely reliable, and under certain circumstances the electric vehicle can show a far lower cost per ton-mile than any other forms of traction. If the Glasgow Corporation Electricity Department will co-operate by providing satisfactory facilities for charging, there seems no doubt of a good demand in the near future. Mr. Craig.

Mr. W. H. L. WATSON: I understand that the recent Glasgow municipal deputation which visited London did not buy electric vehicles because there seemed to be great difficulties about charging the batteries. I know, however, that this is not the case in this city, as there are excellent charging facilities in certain districts, and the fault lies with the city electrical engineer who has not advertised these charging facilities sufficiently. I think also that it would be desirable to indicate where batteries can be charged, even though there are only a few electric vehicles in the city. In my opinion there can be no doubt that in the next few years electrically-propelled vehicles will be used very largely in municipal work. In May of last year I received a letter from the Secretary of the Electric Vehicle Association of America, who stated that there were something like 30,000 vehicles in use; and before Christmas I was informed that there had been an increase of 7,000 vehicles during the interval. If municipalities adopt electric vehicles in the future, they should provide adequate charging facilities for public use as well as for their own cars. Owing to the varied voltages and conditions of supply in this country, it is somewhat difficult to make arrangements at present, but in cities like Glasgow charging facilities are doubtless obtainable. I rarely go into a town without going to the supply station and asking for current and to enquire how long would be taken before the mains could be connected to my car. Sometimes I have waited for three hours, and sometimes for only 10 minutes. Occasionally I am charged 3d. or more per unit, and sometimes the charge is nothing. Mr. Watson

Of course the supply stations cannot at the present stage do much; but having arranged charging facilities, they can ascertain purchase prices, running costs, number of miles per charge, and a host of data which they can submit to their customers, to whom such information might be made very convincing, as they can get at the user in a manner that the manufacturer can never do. Their reward is the sale of the current at off-peak times, and consequently a much improved load factor. As is usual in these matters the centre of operations is in London, where manufacturers are associated and are doing their utmost to foster fellowship and get assistance from central-station engineers. I should like to point out particularly that when electrical vehicles are sold they are supplied with an ampere-hour meter which shows at a glance the condition of the battery in regard to the amount of energy still left unused, and if the car stops for want of current it is to a great extent therefore the driver's fault. An instance occurs to me where a 2-ton van was loaded to the extent

Mr Watson. of 3 tons 5 cwt. The van was capable of doing 40 miles in very dry weather, but 45 miles could be got out of it. The worst road in London was selected for test and the busiest traffic was traversed. It was found that on the average the car was taking 80 amperes on the flat, at the foot of a hill 140 amperes, and on the highest point of it 240 amperes. The van completed 36 miles for 269 ampere-hours at 110 volts, that is 29·5 kw.-hours. The total amount of energy required for the complete charge is 48 units, that is, a cost of 4s. with energy at 1d. per unit. These figures would appear conclusively to recommend the electrically-driven vehicle.

Mr Lackie. Mr. W. W. LACKIE: The Electricity Department of the Glasgow Corporation have had an electric vehicle in use for a year, and from the returns which I have had prepared I am satisfied that this vehicle is doing the work of two horse vans. A horse and van can be hired in Glasgow for from £12 to £14 per month, and the electric vehicle costs about £24 per month; but whereas the horse and van are only available for 10 hours per day from Monday to Friday, for 4 hours on Saturday, and not at all on Sunday, the electric vehicle is available for seven days per week and 24 hours per day. It is agreed that the petrol car has a sphere for which the electric car at its present stage is not suited; but for town work there is no doubt that the electric vehicle has many advantages over the electric car. In Chicago last year I saw (without exaggeration) hundreds of electric pleasure vehicles, and many of these were driven by ladies. It is a common thing there for a lady and gentleman to drive to the theatre, leave the car at the theatre door, and drive home again when the performance is over. Mr. Dalrymple mentions in his Report on his recent tour in the United States that he saw hundreds of people going to business daily in Detroit with their own cars which they left in the street until the time came for returning home in the evening. These, however, were Ford cars driven with petrol. I was told that in Chicago there are 700 electric commercial vehicles and 3,000 pleasure electric vehicles, as against about 1,800 petrol cars. In Glasgow there are about 3,000 motor-cars, 1,600 motor cycles, and 200 heavy motor vehicles, a total of 4,800, all of them petrol-driven, with the exception of the electric vehicle belonging to the Electricity Department. If the cost of the electric vehicle could be brought down to the price of the petrol car, there is no doubt that it would bear comparison in other respects. I would certainly be satisfied with 10 per cent depreciation on an electric vehicle, whereas it is customary to write off 20 to 25 per cent in the case of a petrol car. With electrical energy at 1d. per unit the cost of fuel is one-third what it is for petrol. There is one point about which I am not satisfied at present, viz. the adoption of 110 volts as the standard pressure for charging batteries. This pressure has been taken from American practice, where they have never adopted pressures of 200 and 250 volts for lighting. I think it would simplify matters very much if the battery-makers would supply in this country a battery suitable for plugging on to a 250-volt circuit with a small resistance. Mr. Page has referred to the Edison battery and the lead battery. I learned in New York that one company were prepared to supply either an Edison battery or a lead battery, but the price for the former was much higher, viz. about 3 times, than the price for the latter. The lead battery is guaranteed to do 9,000 miles, and after that it can be renewed for £40. It would appear that if the Edison battery lasts for 4 years, which it is guaranteed to do, it is to be preferred to the lead battery. The cost of a lead battery is £72, and of the Edison battery £201, for a half-ton truck. From the supply authorities' point of view when it is considered that a small electric vehicle will bring in £20, a commercial vehicle £30, and a large van motor £50 per annum, it will be seen that the revenue from these vehicles is well worth cultivating.

Mr. Spence. Mr. W. L. SPENCE: My association with electric-battery vehicles goes back to a three-wheeled two-seated dog-cart designed by Mr. A. B. Blackburn and made in 1897 by the Electric Construction Company, of which he was then General Manager. The control was peculiar: the front wheel was steered with leather reins and was so carried that it tended to run in a straight line. A single pedal brake was provided and the speed was varied by a greater or less pressure on the back-support over the seat. The maximum speed was about 20 miles per hour, and the distance coverable about 30 miles. The photograph exhibited proves it to have been a very presentable vehicle to have been running 16 years ago. It was shown at the Crystal Palace in the year named. Coming to the more modern aspect of the subject, the commercial one, I think that if we are to have electric-battery vehicles generally adopted they will require to be much more moderate in initial cost than at present. I consider that it would be unwise to boost too much the Edison battery, which is practically the subject of Mr. Page's introductory remarks. First cost is very largely considered by prospective purchasers of commercial vehicles; and even if it were universally conceded, as it is not, that the alkaline accumulator is the cheapest in the long run, there would still be scope for the lead accumulator, which can be bought for one-third of the price and has a higher efficiency. Weight is certainly in favour of the Edison type, but when everything is considered the lead-battery vehicle costs less to buy, weighs but little more when loaded, performs as well, and may be no more expensive in ultimate total cost of operation. In connection with the engineering side of the question, the motors used on electric-battery vehicles are invariably series wound, and they are, I believe, never provided with multiple-speed mechanical gear. This I submit is wrong. The storage battery is essentially a constant-voltage contrivance and the motor should be shunt wound in order to suit it. With series-wound motors control is necessarily rheostatic and involves substantial losses. One may have series-parallel control with two motors or with the battery in halves, but that only gives two efficient speeds, and it is much better practice in all cases to keep the battery in a single block charged and discharged as a whole. This can be done quite well with a variable-speed shunt-wound motor used in combination with a multiple-speed gear. As a contribution towards the solution of the problem of a cheap and efficient electric battery chassis I have brought a drawing showing my proposal. The motor will be a small high-speed machine with a variation of 2 to 1, or better 3 to 1. The transmission is by duplicate friction gear of 3 to 1 ratio with two Cardan shafts to two live-axle worm gears and is not provided with a differential. The total speed

Spence. variation may be 9 to 1 without any series resistance losses. This is more than adequate to meet all possible requirements. It means that with a top speed of say 25 miles per hour the speed in traffic may be less than a slow walk—$2\frac{1}{2}$ miles per hour. The system is fully recuperative, braking being dynamic with all the current going into the battery, and, as speed reduction is torque multiplication, there are no undue demands on the battery at any time either for starting or for hill-climbing, hence the distance coverable on one charge will be increased by 15 to 20 per cent at least, probably much more.

A. P. Robertson. Mr. A. P. ROBERTSON: Mr. Page has put the case of the electric vehicle very well before us, although I think only from the point of view of town work. Doctors and professional men would find that the electric vehicle would be much better than the petrol vehicle if they had some method of charging the former at their own homes, because we all know how easy it is to charge up the petrol vehicle. A doctor might run his car 50 miles a day and be called out in the middle of the night. If his car were at the central station or garage to be charged, it would not be of much use to him, and in such a case he would require some means of charging it at his own door. The electric vehicle for a doctor or professional man is by far the best because of the ease of control and the absence of vibration. These are very useful attributes; and in addition the electric car is very much cleaner and it can be started from the seat. This is one of the uses which will bring the electric vehicle into prominence in towns, and I think there is too much made of it as a commercial vehicle only. There are a great many pleasure petrol cars; I do not know the percentage, but it looks as if there were more pleasure cars than commercial ones, and therefore the pleasure cars should not be overlooked. If, however, an owner of such a car found he could only run the car 50 miles on one charge, he would not go in for the electrically-driven vehicle unless there were facilities for recharging batteries quickly. I think that batteries should be standardized. If that were done and some kind of exchange set up, this form of traction would become much more popular. I suggest that roadside depots might be established for the supply of batteries or for charging, something on the lines of the changing of horses in the old stage-coach days. Such a course is necessary, especially with the pleasure vehicle, but standardization of voltage is also necessary. The question of gears also requires to be considered. We should have some method of running the car at low speeds without inserting resistance. A series-parallel system for the battery would solve this and might be arranged in the controller, which would do away with gears; or if this could not be done, then we must have something similar to the gear of a petrol-driven vehicle. As this form of traction is practically in its infancy designers should specially interest themselves in it.

Seddon. Mr. E. SEDDON: We have heard a great deal in the past about smoke nuisance from chimneys, but I think that the smoke nuisance from petrol cars is even more intolerable. I agree with one of the speakers that the shunt-wound motor with the shunt field excited across the terminals of the battery whatever the applied pressure to the armature may be, appears to be the most efficient for electric-vehicle work. I believe that the average lead cell yields from 6 to 8 watt-hours per lb. weight, whilst the Edison cell yields 14 watt-hours per lb. weight, so that the latter type appears to be 100 per cent more efficient than the former. Moreover, Mr. Page's figures show that the cost of Edison cells is about 300 per cent higher than that of the lead type of cells, so that it looks as if the Edison Company would have to reduce the price of their cells if these are to be generally adopted. I notice that present practice with regard to tyres is to use the solid type, even on some of the moderately light vehicles. I think that this is a mistake, as we should do everything possible to increase the mileage of these vehicles; in this respect I should like to quote from a paper read by Michelin, the well-known French tyre-maker, before the International Automobile Congress as long ago as 1900. He gives a number of statistics relative to the efficiency of pneumatic tyres as compared with solid rubber and metal tyres. His experiments are interesting, as showing how the efficiency of the pneumatic tyre in point of traction economy increases directly as the speed of the vehicle. Using an electric wagon weighing 1,980 lb. and a uniform pressure of 80 volts, he obtained the following figures for the tractive effort when running against the wind on a level macadam road over a distance of 1,000 metres :— Mr. Seddon.

Iron tyres	53·9 amperes
Solid rubber tyres	48·5 „
Pneumatic tyres	44·2 „

These results show a saving of 10 per cent for solid rubber tyres and of 18 per cent for pneumatic tyres as compared with iron tyres. The average speed was 7·3 miles per hour. At a speed of 12·3 miles per hour, he obtained a saving of 13 and 28 per cent respectively for solid and pneumatic tyres. Of course, I agree that no one to-day would dream of putting iron tyres upon a vehicle of this kind, but these figures show the advantage of using pneumatic tyres instead of solid tyres. I was surprised to hear Mr. Watson's statement that frequently he could not get his car charged at power stations without waiting some time. I should be very surprised if he could, as there are only a few stations in this country in a position to supply at a pressure of 80 volts or thereabouts, except from large boosters or exciters, which is a costly arrangement. It may eventually be necessary for the battery-makers themselves to provide charging stations; an overall charge could then be made, including maintenance upon a ton-mile basis.

Mr. J. A. ROBERTSON: It is very gratifying, I think, that this important question of battery vehicles is being considered by a committee representing all the interests involved. This is pre-eminently a case for standardization, and although we are very much behind at present, the progress made will be on very sound lines once the industry has become established. One of the reasons why battery vehicles have made so much progress in the United States is the close co-operation which exists between the manufacturers and electric supply authorities. In this country the supply of electricity is largely in the hands of municipalities, and it is therefore more difficult to obtain combined effort. In the past, the tendency has been for the supply authorities and the manufacturers to stand apart; and if this attitude is maintained there is very little hope for the battery vehicle in this country. I believe that the direction in which special Mr. J. A. Robertson.

Mr. J. A. Robertson.

efforts should be made is with the commercial rather than with the pleasure vehicle. Municipalities can do much here by adopting battery wagons for collecting refuse and for purposes such as street sweeping and watering. For these purposes the battery vehicle has enormous advantages and the limitations which exist in the case of the pleasure vehicle are of little importance. I visited the municipal garage at Paris in May of last year and saw several refuse-collecting wagons, one of which had been in operation for two years—the result being sufficiently good to warrant the municipality in ordering a large consignment of these wagons. I think that sufficient justice has not been done to the lead-plate battery. For commercial wagons the greater weight of a lead battery does not constitute a serious disadvantage, and in the later types of cells the heavy discharges do not appear to injure the plates to the same extent. Everybody must recognize the great work done by Mr. Edison in developing his battery, and its unique advantages in the way of lightness and mechanical strength will no doubt lead to its general adoption for pleasure cars, but for the heavier commercial cars I believe that the lead battery will hold its own. The limitations of the battery vehicle must not be overlooked, and it must not be thought that the battery vehicle is at once going to oust the petrol car. For a hilly district the cost of maintenance will be much higher and a larger battery will be required than in a district which is comparatively level. I was impressed by Mr. Page's operating figure of 0·65d. per ton-mile for the Glasgow Corporation's battery vehicle. For a petrol-motor wagon of 4 tons' capacity which has been in use for nearly a year in Greenock, the cost of petrol works out at 2·1d. per ton-mile. Of course the district is hilly, and the battery figure would be somewhat higher than that given by Mr. Page, but it would still show a considerable saving over petrol at its present price.

Communicated: No reference has been made in the discussion to the possibility of using electric batteries for tramcars. In districts where objections are taken on the score of appearance to overhead equipment, the self-contained battery-propelled car should have a large field. The depreciation of the battery should be less and the efficiency somewhat better than when used for road work. In considering a case, it would be necessary to compare the first cost of the battery with the saving in overhead equipment and feeder cables, while the battery losses may be set off against the saving in transmission and the improved load factor to be obtained at the power station where the batteries could be charged during the night. Several trials have been made in America and it would be interesting if we could obtain some information in regard to operating costs.

Mr. Lowson.

Mr. J. Lowson (*communicated*): I can confirm the statement made by Mr. Ayton as to the simplicity of the electric vehicle, its freedom from vibration, smoothness of running, and the consequent lessened wear and tear. This was proved to me about six years ago, when I tested an electric landaulette in London, fitted with an Edison battery of the earlier type. The battery on this car was supplied by the Deutsche Edison Akkumulatoren Company. The capacity was approximately 14 kilowatt-hours with an average discharge pressure of 80 volts. With one charge the car was expected to cover a distance of 56 miles on level well-kept roads when carrying six persons including the driver, and to run at a normal speed of about 16 miles per hour. The battery consisted of 64 nickel-iron cells of the Edison type, containing a 21 per cent solution of potassium bicarbonate, and weighing in all about 11 cwt. The total weight of the complete car was about 30 cwt. It was calculated that the depreciation in the capacity of the battery after two years' running would not be more than 15 per cent. The motor was fixed below the chassis and the power was applied through a reduction gear to the rear axle, giving a direct drive at all speeds. The controller was fixed below the driver's seat, and constructed to give five speeds forward and two reverse. The cost of the above battery at that time was £150, and the price of the complete car £775. If, as Mr. Ayton says, the vehicle of to-day is not to be judged by the experience of even a few years ago, then the electric vehicle is coming to stay, and the sooner the better if petrol is to increase in price at the rate it has been doing lately. It seems to me that the only disadvantage at present of the electric vehicle is its first cost. With reduced prices, charging stations established at all power stations and garages throughout the country, the demand will become very extensive.

Mr. Page.

Mr. A. Page: With reference to charging facilities, Mr. Lackie's suggestion that electric vehicle manufacturers should try to standardize batteries for a pressure of about 200 volts seems the most promising way out of the difficulty if space could be found for the batteries. Where charging facilities are required the Glasgow electricity supply authorities will not be found wanting. There would undoubtedly be a considerable increase in the demand for battery vehicles if the first cost were reduced. Our van cost £560 without the body, which came to about £45, so that the overall price was in the neighbourhood of £600; and we obtained a petrol car to do the same work for about £400. The fact has not been sufficiently emphasized in this discussion that the lead battery weighs at least twice as much as the Edison battery; this will militate considerably against the extended use of lead batteries, and also bears on the question of chassis design and tyre troubles. The strong construction of the Edison battery coupled with its light weight is also greatly in its favour. I do not agree with the use of the shunt-wound motor; and if gear changing is adopted, one of the soundest arguments when endeavouring to sell electric vehicles, viz. their simplicity of control, will be lost. As to pleasure cars, there is certainly a field for electric vehicles for professional men, but the fact is that the majority of those who use cars for business purposes want the car for a run into the country at the week-end. We are just at the beginning and are not yet in a position to give these runs into the country, except where there are charging facilities. Until charging stations are provided we cannot push the sale of the pleasure vehicle. Mr. Seddon said that the ratio of the weight of the lead battery to that of the Edison battery was something like 14 to 8; but it should be remembered that the life of Edison cells is 4 or 5 times the life of the lead type of cell.

DISCUSSION ON

"CURRENT-LIMITING REACTANCES ON LARGE POWER SYSTEMS." *

Manchester Local Section, 7th April, 1914.

Mr. A. E. McKenzie : I think it is not generally recognized that reactances in some part of a large generating system are highly desirable as a means of reducing the disastrous effects of short-circuits when faults occur either on the generators, feeders, or busbars. In laying out a new system I think most engineers will agree that the best place for the insertion of the reactances will be in the busbar sections themselves, because the feeders and generators can be so arranged that there will be very little interchange of power under normal conditions between the different sections. It is a very difficult proposition, however, for those in charge of generating stations where extensions have been taking place for many years, and where machines of larger magnitude have been gradually installed, to determine the positions in which reactances should be placed, because under certain conditions very great interchanges of power will occur between the sections. I am of the opinion that under such conditions it would be better to install reactance coils in the generator leads so as to limit the short-circuit current of the latter to about 7 or 8 times the normal value. Engineers who contemplate doing this, however, should first of all satisfy themselves that the extra field current necessary to compensate for the drop of pressure across the reactance can be carried by the rotor windings without too high a rise in the temperature of the latter. I myself have quite recently made some tests of this nature, and I found it impossible to use reactance coils in the generator leads. If additional reactance is necessary, I think that where group feeders are supplying a number of feeders, reactances of 4 or 5 per cent can be placed with advantage in the group feeders. I think that the authors have perhaps rather magnified the effect of short-circuits on feeders. During the last 12 years at the Manchester Corporation Stuart-street works, about 95 per cent of the faults on the system have, I believe, started through a fault on one phase of a feeder to earth ; and if proper balanced protection is fitted to each feeder, my contention is that in nearly every case the feeder can be disconnected without any consumer on the system knowing that anything has occurred except those on that section which is interrupted. Where the neutral of the system is earthed through a resistance, very seldom need the fault develop into an actual short-circuit between phases. Then with regard to faults on generators which are fitted with balanced protection—and as I have said before, my opinion is that it is the only method which should be used for protecting generators—the same remarks apply : in 99 out of 100 cases the machine will be disconnected before the fault actually develops between the phases ; and if a suitable device is used for switching off the field of the generator immediately the main switch is opened, I think that generator-makers will then have fewer repairs to do in the future than in the past. In my opinion, where a new system is being laid out it will be far better to obtain the reactance necessary to reduce the current on the generators to a safe value by employing high-tension step-up transformers having high internal reactance.

Mr. S. J. Watson : The authors apparently deal only with very large generating stations, because they refer to those having an output of 80,000 to 100,000-kw., and then set out to consider whether reactances should be installed in the generator leads, the feeders, or the busbars. In considering the matter in the light of the diagrams, it occurred to me that in the case of a power station with such a large output the plant should be in sections each quite independent of the others. It does not appear desirable that in the case of a 100,000-kw. plant all the machines should be run in parallel on one set of busbars. Certain conditions might arise where exceedingly large currents would be supplied to a fault notwithstanding the use of reactances, and the supply to consumers taking hundreds of kilowatts would thus be jeopardized. Districts or groups of districts should be independently supplied from separate busbars, and with such a large output I think that the economy of the station itself would not suffer to any large extent, because at times of light load it would still be possible to parallel the different sections so that the main generators would run under satisfactory economic conditions. I should have liked some additional information as to the cost, the dimensions, and the losses in these reactance coils. The largest reactance coil illustrated by the authors on the screen was of only about 400 or 500 kw. capacity, although they mention that reactance coils are made to deal with 20,000 kw. It seems to me that considerable housing accommodation will be required for coils of such a large size. The cost cannot be a light matter and there must be appreciable losses, all of which I think would tend to restrict the use of such coils. Dealing with the question of the necessity for reactances, one of the most important points to consider is whether the generator windings can withstand a short-circuit. The authors refer to this question in several places in the paper, and it seems to me that if the generator end-windings are very strongly bracketed—because this is the weakest part in a machine—there need be very little fear for the generator itself if a rather bad short-circuit occurs. In this connection it is worth while remembering that the present tendency is more and more towards the incorporation of larger reactance in the machine itself. The prime cost of such a machine is appreciably reduced, but one of the arguments against this tendency is, of course, that the machine has much worse regulating qualities. This defect, if such it be considered, can easily be provided for by some form of automatic regulator, and in any case the possibility of injuring the generator windings is thereby considerably reduced. Another point which impressed me is that if in the case of a 10,000-kw. power station 3-phase alternating current is

* Paper by Messrs. K. M. Faye-Hansen and J. S. Peck (see p. 511).

Mr. Watson. being generated at a pressure of 11,000 volts, this output will represent about 600 or 700 amperes, and even with a bad short-circuit the current that can flow into the fault will not be very high. In the case of a similar continuous-current system, however, where the normal full-load current would be about 25,000 amperes, the current on short-circuit would probably be 10 to 15 times greater than the above, and the possible damage would be rather terrible to contemplate.

Mr. Bateman. Mr. W. T. T. BATEMAN: The previous discussion seems largely to have circled round the use of reactances for machine protection, whereas I think it should be considered more from the point of view of the switchgear, since a generator can only deliver, say, 25 times its full-load current (this is perhaps a maximum figure) whilst the switch on a feeder or generator circuit may have to interrupt a current equivalent to many such generators in parallel; thus the greater strain comes upon the switch. Probably the largest ordinary type of oil switch is not capable of dealing with a greater momentary short-circuit output than say 250,000 k.v.a. at the instant of tripping, so that where the momentary k.v.a. output exceeds that figure, reactance is absolutely essential from the switchgear point of view. The authors do not appear to have mentioned a type of reactance which has been successfully used to a considerable extent by the American Westinghouse Company, and which comprises a reactance contained within a compound oil switch consisting virtually of two oil switches in parallel. One element of the oil switch breaks first, leaving the other element in circuit with reactance in series, both the latter element and the reactance being short-circuited in the first position by the former element. This second element finally opens the circuit through the reactance, and the current broken at the time of opening the circuit is thus brought within the limits of circuit-breaker design. I should like to ask the authors, What would be the approximate voltage across the generator terminals during a short-circuit when an external reactance is used in the generator circuit? We know of course that the busbar voltage falls to approximately zero, and it would be interesting to know if a voltage approximately normal would be maintained across the terminals. I should further like to ask the authors, What diminution of the final value of the current of short-circuit is due to the fixed external reactance? We know that in the case of a short-circuit on an alternator the current may fall to approximately $2\frac{1}{2}$ times full-load current, due to armature reaction, eddy current losses, etc. That is, the impedance of the generator increases from the instant of short-circuit until the current falls from, say, 10 to $2\frac{1}{2}$ times its normal full-load value. I should like to know what effect the external reactance in a generator circuit has on the later portion of the curve of short-circuit. With regard to Fig. 10, I should like to know the authors' reason for placing reactance coils in the feeder circuits in addition to reactances in the generator circuits; the only reason that I can see, apart from generator protection, being that an attempt is made to decrease the size of the feeder circuit-breakers over the generator circuit-breakers, the generator circuit-breakers being large enough to handle any fault which might occur on the busbars, and the feeder circuit-breakers any fault which might occur on the feeders, the latter fault occasioning a smaller short-circuit current than the former owing to the additional reactance.

Mr. R... Mr. H. A. RATCLIFF: I should like some further information in regard to the so-called "doubling effect" mentioned on page 511. It appears to be similar to that occasionally obtained when switching on transformers, but I am not quite clear as to the extent of the effect. Is it possibly of sufficient importance to upset calculations relating to the effective reactance of a circuit? If it has the same effect as that obtained with transformers, does it depend upon the previous magnetic history of the circuit, and is it of the same order for both the air-circuit and the partial iron-circuit type of coil? It is difficult to believe that the use of these reactance coils—at any rate so far as the protection of plant is concerned—will be the final solution of the problem. I am inclined to think that in the future design of generators and transformers it will be considered desirable and even necessary to introduce internal reactances for their own protection. Undoubtedly the principal use of reactance coils will be for sectionalizing busbars, and probably also for the protection of switches, for which latter purpose, as Mr. Bateman has mentioned, they can be connected through auxiliary switch contacts and will therefore only be in the circuit momentarily; they can therefore be comparatively lightly built and conveniently enclosed in tanks. One great advantage of external reactance coils arises from the fact that under abnormal conditions the mechanical and electrical strains in a circuit are presumably greatest where the reactance is greatest, and reactance coils are more easily constructed than generators to withstand these strains. It is interesting to note the authors' statement that in the case of transformers the additional internal reactance can be provided without increased cost. There is also one other possible advantage of external reactance coils, namely, under certain conditions it might be desirable to vary the total amount of reactance in a circuit; this would be possible with separate reactance coils, but not in the case of self-contained reactance. Reactance coils for the protection of plant will mainly be used in existing generating stations, and it is therefore perhaps unfortunate that these are the very conditions under which the difficulties incidental to their satisfactory location are greatest. The authors appear to have considerably reduced these difficulties by their particular design of coil; for although in many cases it would be impossible to install the air-circuit type of coil, it would be a comparatively simple matter to install the tank-enclosed and magnetically shielded type. I should like, however, to ask whether the instantaneous reactive effect of the coils under short-circuit conditions is in any way reduced by the presence of iron in the magnetic circuit. It is frequently supposed that reactance in a circuit increases the difficulties incidental to switching operations, that is to say, the greater the reactance in the circuit the more difficult it is for the switch to break the circuit. I hardly think that this is the case in practice, because I think the modern high-tension oil-break switch is far better able to deal with pressure rises than with heavy current rushes, and consequently the reduction in the possible maximum value of the current produced by the reactance coils more than compensates for the possibly increased pressure rise at the switch terminals. It would be a very poor switch indeed

Ratcliff. that was not able to deal with reasonable high-pressure rises across its terminals.

Worrall. Dr. G. W. Worrall: There does not appear to be any necessity for reactance coils in the generator circuit as a measure of protection to the generators, and although their presence would certainly limit the rise of current at the source, there would be a danger of reduced busbar pressure. The authors seem to favour the reactance coils between the busbar sections, but this would introduce considerable difficulties. In order to avoid error in the instruments and heating of the metal due to the stray field, the air-core reactance must not be near the switchboard; yet if the reactance is installed far away the busbars would have to be extended, and this would introduce difficulties from the point of view of safety. The difficulties might not be so great when each busbar is in a separate concrete cell and the oil switches and instruments are on another floor of the building, as in Continental practice. The introduction of inductive reactance into a circuit would certainly affect the operation, and it would appear that some distinction should be made between overhead lines and underground cables. In the former case the line possesses large inductance and small capacity, but in the latter case small inductance and large capacity, the terms "small" and "large" being used merely relatively. The most serious objection to the use of reactance coils appears to be that they introduce another link in the chain, and hence another source of weakness. It should be the aim of engineers to reduce the number of links, not to increase it; and it seems quite possible that the introduction of this additional apparatus, while safeguarding the system in one direction, would weaken it in another. The one may outweigh the other, but that can be settled only by experience.

Mellis. Mr. D. B. Mellis: In my opinion the paper has covered the ground very fully, but there is one point which has not been elaborated, and which seems to me to be of great importance. The function of a reactance coil is to deal with very heavy overloads, and consequently if it is to be efficient its inductance must not vary with the current passing through it. In other words, there must be no iron within the coil, as it would become saturated and the induction density would very soon cease to be proportional to the number of the applied ampere-turns. In the high reactances mentioned in the paper for use between busbar sections an external iron circuit is permissible, as the reactance is so great as to limit the current, in the case of a short-circuit, to a comparatively small value, so avoiding the possibility of the iron becoming saturated. In this case, however, the iron is not inside the coil but external to it, where it has by no means so great an effect in controlling what the inductance of the coil will be. If, however, reactance coils are not used, and generator reactance is relied upon to keep the short-circuit current within bounds, the result will not be very satisfactory, as it is not possible to design a generator which has no iron within the windings of its armature. It must be emphasized that armature reaction is not of value for keeping back the instantaneous short-circuit current, but only armature self-induction, and this is controlled by the induction density possible in the iron within the windings. For this reason it would appear that safety can in no case be ensured without external reactance, the coils of which should be as free from iron as possible. Some speakers Mr. Mellis. have referred to the use of a reactance coil, normally short-circuited, but inserted in the circuit when the oil switch trips, before finally breaking. This arrangement would seem not to meet the situation. While it might be of some use in assisting the oil switch to break a moderately heavy overload (in which case the value of a reactance is debatable, since a resistance would be much cheaper), in the case of a really bad short-circuit on a system with a great generator capacity the reactance would be cut out until the enormous short-circuit current had already attained its full value, and the oil switch would be blown to pieces.

Mr. E. Thomas: It would seem that in point of time our Mr. Thomas. knowledge of this subject is several years behind that of the United States, for we are discussing it as though it were a new matter, whereas it was discussed there at length two years ago and with experience of the behaviour of reactances in practice. It would appear from this paper that the principal importance of the use of reactance arises from the following considerations:—(1) That machines are not safe against the stresses of short-circuit; (2) that under emergency conditions oil switches as now made are not safe protectors of the plant installed; (3) that a shut-down may be avoided by limiting the amount of current that can flow if a feeder or generator breaks down. The paper is written from a manufacturer's point of view, and as the design and construction of machines and oil switches have hitherto been entirely in their hands, the admission of weakness in clauses (1) and (2) must be felt by users of large electrical plant to be very serious and noteworthy. In regard to the machines, it has been agreed that the reactance of the armature itself can be considerably increased. It used to be much greater, and the steady short-circuit current of really good machines by first-class makers was commonly less than twice the full-load current. Better regulation was then demanded; but with the much larger plant and systems now in use it is now recognized as of less importance, and it is agreed that a return must be made to higher internal reactance. Similarly, better clamping and support of the end connections of armature coils are called for and are quite possible. It is not too much to say that no engineer ought now to accept a machine with insufficient internal reactance and coils not supported strongly enough to withstand with a reasonable factor of safety the stresses of infrequent short-circuiting. The low factor of safety of present-day oil switches is a much more serious matter, and their inadequate size would appear to require especial attention. It is well known that with a sufficient length of break well under the surface of an adequate quantity of oil any arc can be extinguished, and experience with the present switches shows how reasonable and practicable the requirements are. Switches that will extinguish emergency arcs will cost more and take more room; but a very moderate extra expenditure with increased provision of space will not be grudged. It is, however, pertinent to ask whether we cannot avoid heavy short-circuits altogether. After discussion with a number of experienced central-station engineers I am satisfied that bad short-circuits in the station itself can be almost eliminated by adopting certain simple precautions. With strongly built machines possessing sufficient internal reactance, with

Mr. Thomas. suitable oil switches, and if the above precautions be taken against short-circuits, the addition of reactance coils will still add a little to the safety of a large station; but to do so they should be very well built and have the phases suitably separated, or they will introduce greater risks than those against which they guard.

Mr. Ferguson. Mr. S. Ferguson: Reactance coils have been introduced because of the very high initial currents that alternators give on sudden short-circuit. It seems to me that it is best to put reactances in the generator leads in proximity with the machine; in the foundations, for example. In the majority of English stations reactance coils could not be installed in the generators, feeders, and busbars as the cost would be prohibitive. There are many advantages in installing them in the generator circuits in preference to the feeder circuits, in addition to those arising from the reduced number required in those circumstances and the ease with which they can be installed. When placed near to the generator the reactance coils protect everything, whilst when placed in the feeder circuits they protect the feeder cables and sub-stations only. It is quite unnecessary to protect these beyond a certain distance from the generating station, as the impedance of the feeder is sufficient to limit the current to a reasonable value. A 2-mile length of 0·15 sq. in. cable is as effective in limiting the current on a 5,000-volt system as a 3 per cent reactance coil. It must be admitted that feeder reactance coils are useful in preventing the busbar pressure from falling if a short-circuit occurs just outside the generating station; but are such short-circuits sufficiently frequent to warrant the large expenditure of installing reactance coils on all the group feeders? It is also generally conceded that feeder faults develop slowly and usually go to earth first. Limiting resistance in the neutral cuts down the current and the feeder is cut off before the fault develops into a short-circuit. On reviewing the serious breakdowns which have occurred in the past it is found that far more have been due to central-station faults than to feeder faults. The former would be taken care of by generator reactances but not by feeder reactances. The drop of pressure on the busbars is not so great if a feeder is short-circuited 1 mile or more from the generating station. To take an example: A short-circuit between two phases 1 mile from the generating station on a 0·15 sq. in. feeder; 30,000 kw. of plant (running at $\frac{3}{4}$ load) 6,000 volt 3-phase, having 6 per cent inherent reactance and 6 per cent external reactance. I estimate that the busbar pressure would not fall initially below about 5,000 volts, and the initial current would be of the order of $3\frac{1}{2}$ times the normal output of the plant. There would, of course, be a further drop in pressure as the armature reaction asserted itself, but the amount would depend on the speed of operation of the feeder circuit-breaker. Another advantage is that the switches on the whole system need only have a smaller breaking capacity. The authors seem to rate busbar reactances according to the capacity of the busbar sections, whereas I believe it is American practice to rate them on the average normal capacity of the generators. The drop in pressure across the reactance is expressed as a percentage of the "star" voltage and not in terms of the "phase" voltage in the case of three-phase systems. The expression "breaking capacity" in connection with oil switches appears also to require a standardized meaning. In practice there is quite a number of interpretations of this expression. The ability of a switch to open a short-circuit on a definite size of plant is largely influenced by the inherent reactance of the generators, as well as by the value of external reactance. These factors should receive consideration when the term is defined. With reference to the short-circuit currents described in the paper, it would appear that no account has been taken of the decreased value of the generator reactance due to saturation at the high currents, so that the short-circuit currents will be somewhat higher than the figures given.

Dr. Rosenberg. Dr. E. Rosenberg: In the early days of electrical engineering there was no need for artificial reactance. The generators regulated badly, and even with full-load current it was difficult to maintain the correct voltage. The same problem occurred in transformers, which when first built had considerable leakage between their high-tension and low-tension windings, and also a considerable pressure drop on the low-tension side for constant voltage on the high-tension side. A large voltage drop occurred on the cables also. The regulation of generators, transformers, and cables has been improved, but improved too much, and the necessity has arisen for introducing new safeguards which, as has been remarked, mean an additional link, and therefore the possibility of new trouble. We certainly cannot revert to previous practice and build machines, transformers, and feeders of such poor regulation as formerly, because our requirements have become more refined, and nearly constant voltage is now required at the consumers' premises. There is no doubt that for the present these additional reactance coils are necessary in many cases in order to limit the effects of short-circuits, but it is not so certain that they will remain a permanent feature. Reactance coils have been introduced previously for paralleling alternators; it was found that reactance coils inserted in generators which were working badly in parallel sometimes removed this trouble, and it then seemed that the provision of reactance coils for alternators running in parallel would be a standard arrangement. Alternators have since been designed which do not require additional reactance for running in parallel, and I believe it to be possible that the reactances mentioned by the authors will disappear in the future. Generators are built which can reasonably withstand the effects of short-circuits, at least if these do not occur too often. With repeated short-circuits of course a cumulative effect will arise and may cause trouble not only on the end windings, but under certain conditions in the rotor also, especially if the rotor is excited from busbars with considerable resistance in series. Transformers are now designed to resist breakdown under "dead" short-circuits. The extremely close regulation that was sometimes asked for has now been dropped, and by increasing the internal impedance from 1 per cent to, say, 4 per cent, the short-circuit current has been reduced from something like 100 times to more nearly 25 times the normal current, and this the transformers will withstand if properly constructed. Additional reactance in the line is necessary merely because our cables have such an exceedingly low reactance. It is to be remembered, however, that before the introduction of the 3-core cable single-core cables were used. Certain serious disadvantages became apparent, but the possibility

berg. remains of designing a feeder with a moderate amount of inherent reactance either by using single-core cable throughout, or by making a certain length of the feeder of single-core cable and only the remainder of 3-core cable. The iron armouring must not be applied in the same way as on single-core continuous-current cables, but the problem of effective sheathing and armouring can be solved for single-core alternating-current cables. Natural reactance is thus obtained, and also increased safety against short-circuits between phases. This can be used for feeders and also for the connection between the machines and the switchboard, introducing there a natural reactance, which although very small is nevertheless useful, especially if the conductors are kept a certain distance apart, and it also does away with trifurcating boxes, which are a source of danger. The appendix dealing with the effect of reactance on the parallel operation of alternators is excellent, and the introduction of the three terms "synchronizing force," "stabilizing force," and "remnant synchronizing force," will make the study of the phenomenon very much clearer in future than it has been hitherto.

s. :n and Messrs. K. M. FAYE-HANSEN and J. S. PECK (*in reply*): We agree with Mr. McKenzie that for extensions it is often difficult to find space for reactance coils, and that it is also difficult to decide how they should be arranged. This is one reason why we have been very careful not to lay down any very rigid rules regarding the position of the reactance coils. Mr. McKenzie mentioned that feeders and generators usually break down first to earth, and that then a suitable protective gear will cut out the fault before it develops into a short-circuit. He is right in stating that most faults are taken care of in this way, but a certain proportion of them are due to mechanical damage. For instance, faults occur through subsidences of the soil or are due to careless workmen, and in such cases very heavy short-circuits may occur between phases, where no protective gear as at present designed will act quickly enough to prevent the maximum short-circuit current flowing. Reliance must in such cases be put upon reactances in the circuit. We agree with Mr. McKenzie that where transformers are used in series with generators it is quite satisfactory, and is good practice to put the necessary reactance in the transformers.

Mr. Watson advocated the division of the supply for very big stations. This is a matter where the central-station engineer ought to be the best judge, but the present tendency is to build such stations with all the machines connected to the same busbars; and there are sound economical reasons why this is done, while there are indications that generating stations of increasingly larger capacity will be adopted. Regarding the size of reactance coils, the 720 k.v.a. reactance coil mentioned would correspond to a 20,000 k.v.a. alternator, so that the size does not work out to be so large as Mr. Watson fears. The cost is certainly a very serious matter, and it is comparatively high because the reactance has not only to be designed for the normal continuous rating but for the kilovolt-amperes at short-circuit, which of course is even much higher than the normal k.v.a. rating of the generator itself. If the normal k.v.a. rating for such a reactance coil be adopted, the cost would approximate to that of a transformer of 5 to 10 times the capacity. The losses in the reactance coils are really very small indeed. Under normal conditions coils of between 5 and 10 per cent of the alternator capacity give between 2 and 4 per cent loss of this rating, so that on the generator itself only a 1 per cent reduction in efficiency occurs, and as the load diminishes the loss is reduced approximately in proportion to the square of the current. It is unquestionable that generators can be made to withstand short-circuits, and more reactance is introduced in these circumstances into the generator, although its regulation is made worse. This is not a very important feature in large generating stations, because fluctuations in load are small, and in addition the regulation is usually effected by means of automatic regulators. It is also true that a cheaper and more efficient generator can be built when the regulation is not such an important requirement. Mr. Watson also refers to the enormous fault current in the case of continuous-current stations. The current may be very large, but it is the value of the kilovolt-amperes rather than the current which has to be considered, and on account of the low voltage of the continuous-current system the resistance in the circuit is always sufficient to keep the number of kilovolt-amperes down to a few times the normal magnitude. Practically in all cases the resistance in the fault is so large that the fault current is not so much greater than the normal full-load current, as is so in the case of high-tension alternators. Messrs. Faye-Hansen and Peck.

As Mr. Bateman says, reactance coils are inserted largely in order to protect the switchgear and to limit the duty of the switches. In this way the cost of the switchgear is often greatly reduced, while in some cases the limit of the breaking capacity of a single switch has been reached, though with the reactance type of circuit-breaker, which is rather an expensive piece of apparatus, we believe that the breaking capacity can be brought up to anything at present wanted. The reactance coil has not only to protect the switches, but it has also to maintain the voltage on other parts of the system during the fault. The voltage on the generator terminals at short-circuit, with reactance-coils in series with the alternator, will depend on the ratio between the armature reaction and the external reactance. Usually it will be something in the neighbourhood of half voltage. With an internal reactance in the generator of 6 per cent and an external reactance of 6 per cent there will be half voltage on the terminals of the alternator with a direct short-circuit. Gradually the generator reactance increases from 6 per cent, and the voltage at the terminals of the alternator falls. Thus the reactance coil has the effect of reducing the instantaneous current at short-circuit to a very large extent. In the case mentioned it would reduce it to one-half, but the reduction in the steady short-circuit current is very small indeed.

Mr. Ratcliff asked about the so-called "doubling effect" and thought that this was the same as that which is met with in transformers. It is the same thing except for this difference, that in transformers when this doubling effect is obtained double the saturation occurs. An air core only doubles the current, but an iron core may increase the current very many times. If the iron core is very near saturation, the value of the current may be very great; but in cases where the iron is far below saturation, as with these choke coils, the current as well as the flux is only doubled.

In reply to Dr. Worrall's question whether any such

Messrs. Faye-Hansen and Peck.

reactance coils have been installed in this country, some have been supplied for the London Electric Supply Corporation, some for the London County Council, and others are installed on the North-East Coast. Dr. Worrall also spoke about the question of stray fields. These will of course have an influence on any instruments near the busbars if the former are not shielded against stray fluxes, but there is no doubt that the introduction of the air reactance coil also introduces the danger of the instruments reading inaccurately. Dr. Worrall also asked about the possibility of resonance. Resonance may occur just as it is possible between alternators, cables, etc., but we think that the probability of its taking place is not increased by installing reactance coils.

We do not agree with Mr. Mellis's statement that for these reactances no iron should be introduced. If oscillograms of the short-circuit currents in alternators are taken, it is found that the current actually has the normal periodicity, and so long as the iron is not saturated it has exactly the same effect under short-circuit conditions as under normal conditions, so that the iron in reactance coils is no more objectionable than the iron in the generators themselves.

Mr. Thomas asked to what extent external reactances limit the forces on alternator windings. In cases where the reactance is of the same order as the armature reaction of the alternators the current falls to one-half and the forces to one-quarter of their normal magnitude. It may be very easy to design an alternator to withstand the short-circuit forces with reactance coils in series, while in special cases it may be very difficult to make it to withstand the forces without the reactances, but we think that at present alternators of any size can be made to withstand short-circuits. We agree that it is necessary to use oil switches which are ample for the duty to be performed, but the duty may be much less when reactances are used. We think that it would be unwise to design a very large station without reactance coils unless transformers are used which are designed with the necessary reactance.

Messrs Faye-Hansen Peck.

Mr. Ferguson mentioned that feeder reactances should not be installed because the resistance of the feeder itself limits the short-circuit current. For a 6,600-volt cable one mile long this is true, but it is very likely that with 6,600 volts a breakdown might occur very much nearer to the station, and the higher the voltage the greater is the danger zone within which the damage might be serious in case of a short-circuit. It is very difficult to say what is the best way of rating busbar reactances, but it is necessary to express the rating clearly. In the paper we have adopted the total capacity of the busbar section as a standard. We think that for busbar reactances it is much better to refer the size of the reactances to the size of the busbar sections rather than to that of the alternator, as there may be one or ten generators on that section and the action depends entirely on the full output of the section. Regarding the breaking capacity of the switches, we agree that this also ought to be stated clearly ; probably the best way of doing so would be to state the ultimate kilovolt-amperes which could be broken without rendering the circuit-breaker unfit for service.

THE NEW CENTRAL TELEGRAPH OFFICE, CALCUTTA; AND STANDARD FITTING AND EQUIPMENT OF TELEGRAPH OFFICES IN INDIA GENERALLY.

By C. T. WILLIAMS, Member.

(*Paper read before the* CALCUTTA LOCAL SECTION *5th February*, 1914.)

ABSTRACT.

For several years past the Indian Telegraph Department has been introducing standard fittings into offices, and the new Central Telegraph Office just opened in Wellesley Place, Calcutta, is fitted on standard plans. It is representative on a large scale of the fitting of all offices of any importance in the Department. On the ground floor of the new building there are three entrances, one on the west into the public counter hall, one on the north for the operating and general staff, and one on the south for offices and officers' residences. At this entrance an electric lift gives access to all floors, besides which there is a staircase of reinforced concrete.

The ground floor contains the public hall, the battery and power rooms, the cable room, the workshop, and various dining and retiring rooms for the staff.

On the first floor are the instrument room, message office, cloak room and lavatories, volunteer armoury, the superintendent's and other offices, and a small workshop.

The instrument room is 150 ft. long by 75 ft. wide, and its floor, like all the others in the building except the ground floor, is built on the "Kleine" patent hollow-brick system, covered with $1\frac{1}{2}$ in. of Indian patent stone. The second floor, which is really a mezzanine floor, opens at each end to the instrument room, forming a kind of balcony looking down into it and adding to its apparent size, besides being an additional source of ventilation.

The third floor can later on, if necessary, be used as additional galleries of the instrument room. It is at present divided up into smaller rooms for offices.

The fourth floor, to which access is gained by staircases from the third-floor corridor, contains the quarters of the superintendent and other resident officials.

LIGHTING.

The instrument room has abundant light from windows and upper wall lights on the east and west, the windows all being fitted with the usual "Jilmil" shutters for use as sun protection. All walls and roofs are white throughout. Artificial lighting is supplied by 52 inverted reflector pendants with opal shades below and white enamelled dispersing reflectors above, each pendant containing three 50-c.p. Osram lamps.

ELECTRIC FANS.

In the instrument room are 52 three-bladed ceiling fans on a level 1 ft. below the lamp pendants and one fan per 87 sq. ft. of superficial area at a height of 11 ft.

CABLE ROOM.

On the ground floor there is a cable room into which come seven paper-insulated Callender's 20-conductor cables, lead-sheathed. These are terminated in standard pattern cast-iron boxes filled with paraffin wax with porcelain-insulated terminals. From the terminals the connections to the distribution frame are made by means of 5-conductor No. 20 S.W.G. lead-sheathed cables with I.R. insulation, passing through a trough to the frame. These wires are attached first to a heat coil, and then to the bar of a lightning discharger of the usual pattern, the details of which are shown in Fig. 1. From the front panels of the frame on which the above appliances are carried, connections are made by means of "jumper"

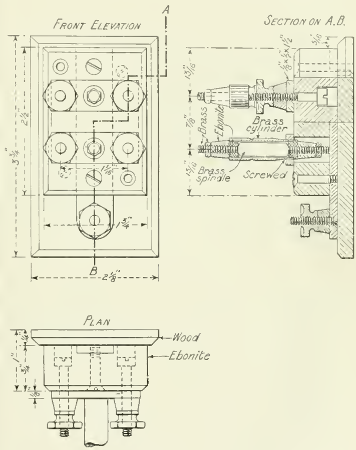


FIG. 1.—Lightning Discharger.

wires to the back panels and thence upstairs to the office "line switchboard" by 5-conductor lead-sheathed cables.

The lightning discharger consists of the small brass cylinder shown in Fig. 1 through which passes a spindle 239 mils in diameter. The air-space between this and the body of the cylinder is 5 mils. The cylinder is screwed into the brass plate to which the line wire is attached, and the insulated rod referred to then makes contact with a common earth-bar fitted underneath. These small-capacity dischargers have been found to be sufficient protection generally in the plains, but for hill stations, where lightning is very much more prevalent, special

plate dischargers with choking coils are used. Of course the far ends of the cables are also protected.

Earth Connections.

In the cable room the earth wires coming from the switchboard (three 7/18 S.W.G. cables) are joined to the two main earths X and Y by cables of four strands of copper wire weighing 300 lb. per mile. The Z or auxiliary earth is formed of a coil of galvanized iron wire buried some distance away in a hole filled with charcoal. Connection is also made with the iron frame of the cable end boxes. The earths X and Y are formed by two $\frac{3}{16}$-in. thick galvanized iron cylinders buried in charcoal, each being furnished with two copper straps riveted and soldered. One of these cylinders goes down about 12 ft., well below perpetual water level; and the other not so far, as it was found to be impossible to dig so deeply. Provision has been made for watering it by means of a drain in the dry season. The earth X is joined to the instrument tables by 4 strands of 300 lb. per mile copper wire looped all round the instrument room, and the connection to each table is by means of a yard or so of 7/18 S.W.G. cable, so that the resistance is inappreciable. The earth Y is connected to the centre of the battery. The use of three separate earth-wires is generally practised in the Indian Telegraph Department to provide facilities for testing the resistances of the earth-plates. Normally all are joined in parallel, to reduce resistance and to avoid a failure of communication in the event of a leading wire breaking, but for purposes of test $X + Y$, $X + Z$, and $Y + Z$ can be taken, and having tested these three pairs by a Wheatstone bridge, or other method, it is easy to calculate the resistance of either X, Y, or Z. The maximum permissible resistance generally is 10 ohms, but the author has known a case where on a rocky plateau the earth resistance was as high as 1,500 ohms.

Battery Room.

The battery consists of 200 Tudor J2 cells with a capacity, on light discharge, of 73 ampere-hours. This battery, being earthed at its centre, gives a "positive" and a "negative" battery of 200 volts. Voltages are tapped off by lead-sheathed wire 1/18 S.W.G. carried along the battery stands or porcelain cleats to the fuse box and thence upstairs to the battery switchboard by lead-sheathed wires.

The walls or plinths carrying the battery stands, as well as the floor, are coated for $1\frac{1}{2}$ in. with special cement made of $4\frac{1}{2}$ parts of quartz sand to one of Portland cement. This is said to be less liable to be attacked by spilt acid than ordinary cement. The floor slopes towards a common drain and the plinths and floor can be washed down with a hose pipe. The battery stands are of teak painted with 4 coats of acid-proof paint. They are of section $3\frac{1}{2}$ in. deep by 2 in. wide.

The battery leads are 7/18 S.W.G. cables, lead-sheathed and rubber-covered, protected by a special 25-ampere fuse.

The voltages supplied to the switchboard in the instrument room are:—

Positive: 8, 20, 30, 40, 60, 80, 90, 100, 110, 120, 140, 160, 170, 180, and 200.

Negative: the same but omitting the 8-volt point, which is used for local bells and automatic switches.

The charging takes place in groups of 40 and 20 cells. Starting from the earthed centre of the battery we have $+A = 40$ cells; $+B = 40$ cells; $+C = 20$ cells; and similarly 3 groups on the negative side. The reason for charging them in this way is that the bulk of the discharge comes on the 0 to 80-volt and 0 to 160-volt points. The 160 to 200-volt portions are used only for the "Wheatstone Automatic" and the "Baudot" systems during such times as the insulation of the telegraph lines is exceptionally low and the received currents at the distant ends are weak. These two 20-cell batteries are therefore charged only occasionally as required.

A special battery of 15 cells is provided on a separate stand for driving the motors of the "Baudot" instrument.

Machine Room.

In the machine room there is a large switchboard for the three sets of mains which supply the three motor-generators. Two of these pairs of mains are 7/18 S.W.G. and one pair are 3/18 S.W.G. Henley cables. The switchboard has three panels for the three motor-generators and other panels for charging any sets of cells. There are two motor-generators driven at 220 volts and capable of supplying 20 amperes at 120 volts. There is a smaller machine driven at 220 volts at 6·6 amperes and capable of giving 50 amperes at 15 volts. All machines are fitted with field regulators for varying the voltage on the secondary side. The two first-named machines are used for charging the J2 cells at 18 amperes, and the small one for charging groups of 5 "S.G.3" cells at anything up to 20 amperes.

The "Baudot" motors, 20 in number, take about 1 ampere each, and as the Chloride "S.G.3" cells have a capacity of about 120 ampere-hours it is sufficient if 5 cells are charged daily for a short time. There are a few other small motors for the Wheatstone automatic; the "Creed perforator receiver"; the "Gell" Wheatstone transmitter, etc., which are operated from the main battery; but the policy now is to get all motors wound for 220 volts as far as practicable, so that use can be made of the ordinary electric supply.

Workshops.

The larger repairs are done at the large factory at Alipore, where about 1,000 men are employed in constructing telegraph posts (steel galvanized), wireless telegraph steel masts up to over 264 ft. high, castings, furniture, cable, and apparatus of all kinds. The repair department is always busy, as the whole of India and Burma send repair jobs there. At the Central office there is a workshop next to the machine room with half a dozen Indian mechanics; and there is a small workshop in a room behind the main switchboard, but only one "Baudot" mechanic is usually kept there, to be ready for demands requiring immediate attention.

Instrument Room.

The addressing and gumming of messages is done in the instrument room by people seated on either side of a 30-ft. table. This has a trough down the centre, in which runs an endless belt, so that as the messages in their envelopes are got ready they are thrown into this trough and shot out at the far end for dispatch.

The switchboard is divided into three panels, the right

and left ones being for the battery and the central one for lines and instruments. The voltages required can be tapped off to any particular instrument or group of instruments by means of cord plugs fitting into brass thimbles, which are permanently connected together at the back of the ebonite panel by brass discs. There are also a number of battery points connected permanently to corresponding sets of apparatus. For coupling up a number of tapping-off points **U**-links are used, whilst any special voltages may be taken off by the cord plugs.

There are 1-ampere fuses fitted on most of the circuits, while the main fuses in the battery room are of 5- and 10-ampere carrying capacity. The wires to the battery room and the cable room go direct from the back

The separators are 12 in. apart and the method of wiring is to pass the wire inside them and bring it out round the separator which is nearest to the point of application and then through a $\frac{1}{4}$-in. hole in the table to its terminal. This system enables wiring to be done quickly and renewals and changes to be made easily.

For carrying typewriters (of which a large number are used for receiving from Morse instruments instead of writing messages), special recesses are provided on the tables as shown in Fig. 2. Revolving-arm sounder-holders are used with these, which can be adjusted to any height or angle to suit the receiving telegraphist. The typewriters are "Remington," specially made with capital letters only and a special paper roller and tearing-off apparatus. There is

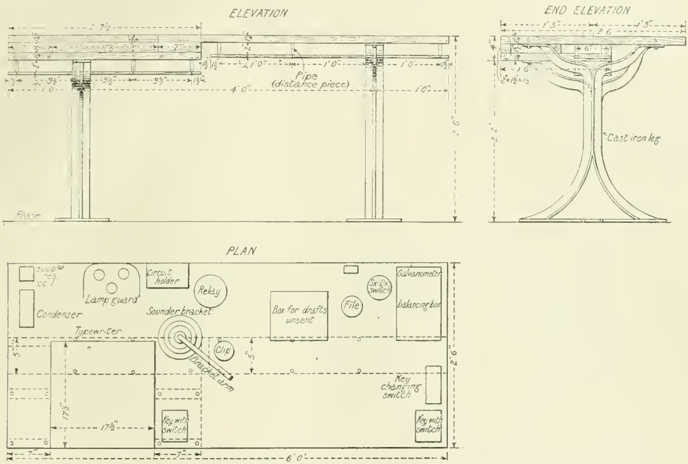


FIG. 2.—Instrument Table showing Typewriter Recess and Arrangement of Apparatus for Simplex-Duplex.

of the switchboard. Also 5-conductor lead-sheathed rubber-covered cables go by steel-lined troughs in the floor to the ends of the instrument tables. There are two troughs 15 in. by $3\frac{1}{2}$ in. one on each side of the room. The troughs are cement-lined and fitted with a sheet steel trough with cover. A bridge piece is fitted opposite to each table on which is riveted a $2\frac{1}{2}$-in. diameter iron pipe up which the cables go to the table level. Thus the conductors are well protected, and the floor could be flooded with water (in case of fire) without injuring anything.

The instrument tables are of special design (Fig. 2). The legs are of cast-iron and up the centre of the under surface is a wooden wiring trough, consisting merely of a board 6 in. wide separated from the table by 2-in. pieces of pipe through which a wood screw passes.

no duplicate copy; the original is delivered to the addressee and only a skeleton copy of the particulars, *i.e.* prefix, time, etc., made by a special clerk is retained. There are 32 simplex-duplex sets of apparatus in Calcutta so fitted.

The instrument room comprises a Wheatstone automatic section with all the Wheatstone apparatus and two "Creed's Perforating Receivers."

SYSTEMS IN USE.

Morse system.—There are in India and Burma thousands of small offices known as combined Post and Telegraph Offices, and in these the single-current closed-circuit system of Morse is almost entirely used. The battery, as a rule, is at the principal office and except at fairly large offices, where accumulators are used, it is of the Minotto type of Daniell's cell. Normally a current of about 10 to

15 milliamperes is flowing in the circuit, and the armature of the sounder (wound to 500 ohms) is held over against the pull of a spring. On a station pressing the key the circuit is broken and all sounder armatures fly over to the opposite side and give a dot or a dash according to the length of time during which the key is pressed. In the Dubern sounder, which is generally used, the armature is pivoted vertically so that it moves in a horizontal plane, but the ordinary form of sounder may of course be used. The Dubern pattern is particularly sensitive owing to the pole-pieces being arranged to give a pull on opposite ends of the tubular armature. As many as six stations are joined in series.

Polarized sounder-condenser working.—Fig. 3 represents the latest system in use for small offices on lines which are not very long, say up to 200 miles in length, and of which the insulation is good. Normally the line is attached through a 2,000 or 3,000-ohm coil to the battery of about 100 volts so that the condensers are all charged.

The function of the condenser is to return the sounder armature to its normal position of rest near its upper stop, but the actual pulling down is done by the battery current. The current can be made very small indeed because, as it is unnecessary to employ a strong spring to return the sounder armature to its rest position, it can be, and is, so adjusted that it remains indifferently either at the rest or the working stop. Closed-circuit Dubern sounders are gradually being replaced by Vyle's sounders, which in fact are becoming the standard Morse instrument for all purposes. They are wound differentially and to a high resistance, so that they can be worked *direct* on duplex circuits up to about 400 miles in length.

Concentrator system.—For working a number of wires connected to small offices with very little traffic use is made of the "concentrator." There is only one at present in Calcutta. It is connected to 28 "combined" office circuits and these are worked by 12 sets of apparatus instead of 28. No circuit has more than four stations

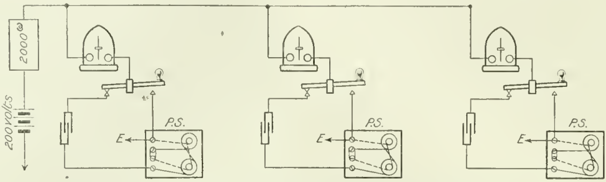


FIG. 3.—Single-current Polarized Sounder with Condenser.

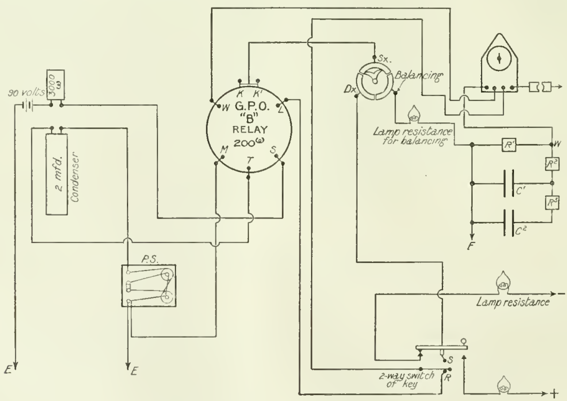


FIG. 4.—Double-current Simplex-Duplex.

altogether, that is, three besides Calcutta. When an office has a message he calls CA and this causes the needle of a single galvanometer (or indicator) to oscillate. The attending operator at the concentrator puts his own sounder plug in and answers; if all sets of instruments are engaged he takes the message himself: if not he plugs the line on to a vacant instrument and the message is taken by the operator there. On completion, the operator presses a push button which causes the line to be again connected to its indicator.

Simplex-duplex double-current system.—For long lines the double-current system is used, and Calcutta has nearly 60 such circuits. The author thinks that the connections have been simplified about as far as they possibly can be (Fig. 4). The condenser is normally charged, and on the relay tongue going to marking or M the condenser discharges through the sounder and actuates it. By this method of working great economy of battery power is effected. It will be noticed that two signalling keys are fitted on the special duplex tables for typewriters, together with a switch for changing from one to the other. This is convenient because it permits of single-handed working when desired. The receiving operator can stop the sender.

The Wheatstone automatic system.—The system is worked up to about 150 words per minute between Calcutta and Bombay, and at anything up to 100 between Calcutta and Rangoon (1,110 miles). There is a repeater at Akyab; and, on the route *via* Mandalay, which is about 1,600 miles long, there are repeaters at Gauhati and Mandalay. The system is used for ordinary traffic and news, the latter especially. As an example of its use, on the arrival of the weekly mail from England a large consignment of perforated tape prepared in London is received at Bombay, is at once passed through the transmitters to Calcutta, Rangoon, Madras, and other places *en route*, and appears in the Friday evening and Saturday morning issues of newspapers as "News by the Mail."

The system has been in use since 1900, and reports of council meetings, speeches, etc., are transmitted by it. The receiver tape is written up by hand, or is typed up; and the speed at which work is turned out depends upon the number of writers or typists employed. It was of the utmost use during the Coronation Durbar. On this occasion the news for English papers was received at Bombay on a Creed's automatic-perforating receiver and the punched tape was then reproduced at about 90 words per minute. This tape was handed to the Eastern Telegraph Company, passed through a machine called a Creed's translator, which turned out tape punched with holes suited for cable transmission, and was then passed through cable transmitters to Europe *via* Aden, Suez, and Alexandria.

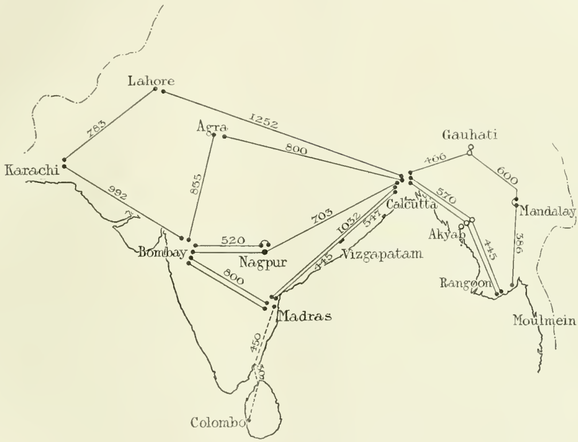


FIG. 5.—Installation of the Baudot System.

On Fridays most of the English mail news for Rangoon is received at Calcutta on a Creed's perforating receiver and as soon as it is received it passes through a transmitter on to Rangoon. In fact one end of the tape is in the transmitter as soon as it is long enough to reach it, and reception and transmitting goes on simultaneously. "Creed's Printers" are about to be installed at Calcutta and Rangoon, which produce by aid of the perforated tape a typed tape at about 90 words a minute. The motive power for all Creed's apparatus is compressed air; and at Calcutta a high-power air compressor capable of

driving several such sets at a time has recently been installed.

There are two sets of automatic high-speed repeaters at Calcutta which enable Bombay, Madras, or Simla to work to Rangoon when necessary for special press.

It might perhaps be mentioned that the bulk of the Indo-European Company's traffic between Karachi and London and Manchester is done by this system, there being no less than 14 automatic repeating stations between Karachi and London. In January, 1909, an interesting experiment was made one Saturday night by joining Karachi through to Calcutta *via* a repeater at Agra, and London was worked through at about 35 to 40 words per minute. After some time London was asked if they would like to speak to Rangoon, and, as they were agreeable, by joining through repeaters at Calcutta and Akyab, London and Rangoon worked both by tape and hand perfectly and exchanged complimentary messages "from the Orient to the Occident." It was quite the *entente cordiale*, and as an interesting experiment in land-line telegraphy has probably never been surpassed. The length of line was over 8,000 miles. The speed obtained was 27 words per minute in one direction and over 30 in the other.

Baudot system.—The Baudot printing telegraph has been in use on the Continent of Europe for many years and was introduced to India in 1905. It is now the most valuable system for ordinary traffic and is in use on the circuits shown on the rough map (Fig. 5). The messages are printed in Roman capitals on a paper tape which is gummed on to telegraph forms. Although fairly complicated the receiver is a marvel of robust workmanship and—for what it does—of simplicity. Given a line free from interruption the amount of work that can be steadily done is most satisfactory. An average of over 150 messages per hour for 20 hours on end have passed between Calcutta and Rangoon; and 120 is common. There is no strain on the receiving operator and the sending operators get so used to the keyboard that it is easy for them to be sending one message and discussing corrections in another at the same time. The author does not mean to infer that this is a usual practice, but it is an easy feat. There are several works on the system, both in English and French.*

* POULAINE and FAIVRE—"Cours d'Apparcils Baudot"; C. T. WILLIAMS—"The Baudot Printing Telegraph"; HODGE and D'ROZAIRO—"Baudot Multiplex Printing Telegraphs"; A. C BOOTH —The Baudot Telegraph System Duplexed. *Post Office Electrical Engineers' Journal*, vol. 3, p. 336, 1910-11; PENDRY—"Baudot Printing Telegraph"; Departmental Code Book, Indian Telegraph Department—"Hints on Practical Baudot Working."

The author may add that, although the Baudot system works well over 1,000 miles of copper wire without a repeater, it is found to be advisable to use one on some circuits. A special form of repeater is in use, but an ordinary fast duplex Morse repeater can be used. It is first balanced on a Wheatstone set of apparatus and is then switched over to work Baudot. It works quite well, but the drawback is that one cannot read what is passing, so the regular Baudot repeater is preferred where a Baudot receiver can be switched in so that the printing of the passing messages can be observed.

The Indian Telegraph Department was one of the first outside the Continent of Europe to adopt the Baudot system and they have never had cause to regret it. At least one-fourth of the traffic of the Calcutta office is done on it with only 8 or 9 sets of apparatus.

They had for some time in use the Murray automatic printing system, which printed messages in column on a typewriter.

Other telegraph offices.—The author has dealt with all the systems in use at Calcutta and this is necessarily representative of those at other large offices. The most important improvement during the last few years has been the substitution of accumulators for primary cells at most offices of importance. In the smaller offices there is a standard charging plant consisting of two Hornsby-Akroyd $2\frac{1}{2}$-b.h.p. oil engines driving Crompton belt-driven shunt-wound dynamos giving 8 amperes at 135 volts. At some of these offices a few lights are installed and perhaps one or two fans as well; but usually when such an office is now refitted a direct-coupled Lancashire shunt-wound dynamo, driven by a Bellis & Morcom oil engine and giving 27 amperes and 75–108 volts at 900 revs. per minute is installed, and from this the lights and fans for the office can easily be supplied. Most of these offices are of the second class, closing normally at 9 p.m., and the only load—besides telegraph repeaters—after 9 p.m. consists of two or three lamps and a fan for the men in charge of repeaters. The battery used in these offices is generally 200 Tudor J1 cells earthed at the centre and having a capacity of about 20 ampere-hours.

In this paper the author has omitted all reference to outside construction work and has said nothing about the many cables in use for crossing wide rivers, the long spans of steel wire carried by high masts built of tubular steel or of old railway rails, but he has, he hopes, given a fair idea of what is being done by this important public department.

EXAMINATION PAPERS SET AT THE ASSOCIATE MEMBERSHIP EXAMINATION, MAY, 1914.

ENGLISH ESSAY.

(*Time allowed : 3 hours.*)

INSTRUCTIONS.

Not more than TWO *questions to be answered. One essay of merit will suffice to obtain a pass.*

The maximum number of marks obtainable is the same for each question.

Marks will be awarded for grammar, spelling, punctuation, clear and simple style, orderly presentation of facts or arguments, and power of expressing ideas in good English. Candidates are not necessarily required to have special or technical knowledge of the subject-matter of their essays.

1. Discuss the future of aviation, in peace and in war.

2. A common saying is that "History repeats itself." How far is this saying true or false?

3. What is the value of mathematics in science, and what are its limitations, more particularly in respect to engineering science?

4. Should our railways be nationalized?

5. Write an account of the life and character of any person well known in history, science, or literature.

TRANSLATION FROM FRENCH.

(*Time allowed : 3 hours.*)

Candidates should follow the original French; but if the literal translation should appear awkward or obscure, they should explain their meaning.

A.

On admet généralement ce principe dualiste d'avoir dans une dynamo deux organes dont les fonctions sont bien distinctes: l'inducteur et l'induit; l'un d'eux est ordinairement le stator et l'autre le rotor.

Cela n'est cependant pas une nécessité physique; il suffit que le bobinage de l'induit soit en mouvement dans un champ qui ne coïncide pas avec son champ propre; c'est ainsi, par exemple, qu'un alternateur produisant du courant réactif s'excite sur son propre induit.

Un exemple de machine à excitation interne est le suivant :

Un anneau Gramme à deux collecteurs est entouré d'un anneau de fer ; on envoie du courant continu dans un des collecteurs : il se produit un champ magnétique et l'anneau en mouvement donnera une différence de potentiel entre des balais calés sur le second collecteur à angle droit des premiers. Mais si l'on fait débiter du courant au second collecteur, son enroulement tendra à agir comme inducteur sur l'autre, ce que l'on évitera en plaçant un enroulement compensateur du second enroulement sur l'anneau extérieur. D'autre part la machine peut aisément être rendue auto-excitatrice.

On peut réaliser aussi une machine à excitation indirecte : Soit un induit à collecteur compensé par un bobinage Ryan disposé dans le stator ; en plus des balais normaux, disposons à angle droit deux balais transversaux en court-circuit sur le même collecteur. Si la compensation est un peu surabondante, le flux dû à l'excédent est inducteur par rapport aux balais en court-circuit, et il suffit d'un faible champ de surcompensation pour obtenir un fort champ excitateur transversal qui sera utilisé pour la production du courant par les balais principaux et l'enroulement de compensation.

B.

Il s'agissait à Lyon de réunir l'énergie provenant de huit stations centrales hydrauliques indépendantes, pour la distribuer sur de vastes réseaux dont les lignes convergeaient à Lyon, point extrême de la distribution.

En raison des variations de saison des débits des diverses stations génératrices, il était nécessaire de coupler ces dernières pour profiter des hautes eaux des unes en été, ou des réserves d'eau accumulées par les autres en hiver.

Avec le système de distribution par courants triphasés, il aurait été nécessaire de faire travailler toutes les usines en parallèle, avec le risque de voir le service général interrompu ou compromis en cas de court-circuit ou d'accident sur une ligne.

C'est pour obvier à cet inconvénient que le système courant continu série a été choisi et, comme il s'agit là d'une application spéciale réalisée pour la première fois, car l'installation remonte à 1905, il est intéressant d'insister sur le caractère particulier qu'elle présente et qui met en lumière un avantage offert par le courant continu série.

Des huit stations génératrices hydrauliques de la Société, cinq furent équipées en courant triphasé transporté à 45,000 volts, et trois furent installées avec du courant continu série 150 ampères constants et avec une tension pouvant atteindre 100,000 volts pour une distance de transport de 200 km.

Quinze groupes récepteurs furent installés à Lyon, dont six placés au centre de la ville et alimentés par un câble souterrain, haute tension, placé directement en prolongement des lignes aériennes de transmission.

C.

La présente Note a pour but de faire connaître une méthode nouvelle de chauffage électrique permettant d'éviter l'usage dispendieux du platine dans les fours à résistance métallique et d'atteindre des températures plus élevées qu'à l'aide de ce métal précieux.

Le chrome est, en effet, moins fusible que le platine et très peu altérable ; tandis que ce dernier ne peut être échauffé sans danger au delà de 1,600°, le chrome paraît pouvoir fournir des températures voisines de 2,000° ; mais

l'absence de malléabilité et de ductilité de ce métal, qui rend impossible l'emploi de lames ou de fils, en a fait rejeter l'emploi.

Il paraît cependant souhaitable qu'à côté des fours à arc engendrant plus de 3,000°, les laboratoires possèdent des fourneaux à résistance métallique, peu coûteux, fonctionnant avec un ampérage modéré et pouvant être chauffés directement à des températures inférieures ou supérieures à 2,000°; l'étude approfondie des réactions endothermiques des fours électriques serait facilitée par ce fait.

Dans ce but, nous nous sommes proposé d'utiliser, comme substances chauffantes des fours à résistance métallique, *les poudres granuleuses des métaux réfractaires*: chrome, molybdène, tungstène; les essais préliminaires que nous résumons ici ont porté sur l'emploi du chrome, aluminiothermique, concassé, pulvérisé au broyeur à boulets, débarrassé de fer par l'aimant, puis trié au tamis; nous espérons revenir bientôt sur l'emploi des autres métaux réfractaires.

On sait que si l'on veut faire passer un courant appréciable à l'aide d'une force électromotrice modérée à travers une masse de grains métalliques, il faut comprimer la poudre; celle-ci obéit à la loi d'Ohm à partir d'une pression minimum dépendant de la nature et de la grosseur des grains. Mais l'emploi de la pression pour frayer au courant son chemin à travers le métal ne serait pas pratique dans le cas d'enceintes chauffantes de formes variées. On peut s'en affranchir par plusieurs moyens.

D.

Dans une Note précédente, j'ai montré que l'écoulement dans un tube capillaire, sous une pression élevée, de solutions même très concentrées de sulfate de cuivre dans l'eau, produisait entre les extrémités du tube une différence de potentiel: 1° proportionnelle à la différence de pression; 2° d'autant plus petite que la solution est plus concentrée.

J'ai fait depuis des expériences avec des pressions pouvant atteindre 300^{atm} et j'ai mesuré la différence de potentiel produite par l'écoulement de solutions contenant jusqu'à 1 molécule-gramme de sulfate de cuivre par litre. Si l'on porte en abscisses les concentrations en molécules-grammes par litre, en ordonnées la différence de potentiel correspondante rapportée à 1^{atm}, on obtient une courbe de forme hyperbolique ayant pour asymptotes les deux axes de coordonnées. La même forme de courbe se retrouve pour les solutions de sulfate de zinc, d'azotate de cuivre. Le Tableau suivant donne, pour une différence de pression de 1^{atm} et pour diverses concentrations, les valeurs en volts de la force électromotrice de filtration correspondante à chaque sel.

Les forces électromotrices mesurées ne dépendent que de la pression et de la concentration, mais non de la longueur et de la section du tube.

Lors de l'écoulement des solutions de sulfate de cuivre et de zinc, le potentiel à la sortie du tube est plus élevé qu'à l'entrée, indiquant un transport d'électricité positive dans le sens du courant liquide; mais il n'en est pas ainsi pour tous les sels. Les solutions d'azotates de cuivre et de zinc, de chlorure cuivrique produisent une différence de potentiel en sens inverse.

MECHANICS, PHYSICS, AND CHEMISTRY.

Every candidate must take Section A together with either Section B or Section C.

(*Time allowed: 3 hours.*)

Section A. APPLIED MECHANICS.

(*Not more than* FOUR *questions to be answered.*)

1. State the laws of friction of solids on solids. Two bodies, A and B, are connected together by a light chain and are pulled along a horizontal ground by another chain attached to A. Find the acceleration due to a pull of 100 lb. weight, the weights being, $A = 80$ lb. wt. and $B = 90$ lb. wt., and the coefficient of friction between each body and the ground being $\frac{1}{2}$. Also find the tension in the connecting chain.

2. Explain how the principle of the conservation of energy is employed in calculating the change of velocity during movement along curved surfaces.

A heavy ball is suspended from a fixed point by means of a light chain. Prove that if the ball be withdrawn from its equilibrium position through any angle of 90° or less and then let go, the velocity gained in falling to its lowest position is proportional to the chord of the arc of fall.

3. Prove that the motion of the centre of mass of a body is the same as that of a particle of mass equal to the total mass of the body acted upon by the vector sum of all the forces acting anywhere upon the body.

A square plate A B C D (side $= 2$ ft.) is acted upon at A by a force of 2 lb. wt. which acts parallel to A B, and at B by a force of 3 lb. wt. parallel to C D. Find the acceleration of the centre of mass, the total mass being 40 lb.

4. Define moment of inertia and explain the part it plays in connection with the rotation of rigid bodies.

A garden roller (mass $= 1$ cwt.) is pulled up a lawn whose inclination is 5 in 100. If the handle is inclined at an angle of 45° to the ground find the force required to move it, assuming the rotating part to have a weight of $\frac{1}{4}$ cwt. and a spin-radius (*i.e.* radius of gyration) of 1 ft.

5. Define simple harmonic motion.

A piston moves backwards and forwards with approximately simple harmonic motion through a maximum range of 4 ft. in half a second. Write down an equation for the motion; also one to give the velocity at any instant; and calculate the kinetic energy at distances of 1, 2 and 3 ft. from the end of the stroke; the mass of the piston being 200 lb.

6. Define the metacentre of a floating body and explain how its position can be ascertained from theory.

Prove that a cubical block of wood will not float horizontally in water although it does so in mercury. Take the specific gravities of wood and mercury as 0·5 and 13·6 respectively.

Section B. PHYSICS.

(*Not more than* FOUR *questions to be answered.*)

1. State the principal properties of saturated and unsaturated vapours.

A mixture of air and water-vapour is enclosed above the mercury in a barometer tube whose open end is immersed in a deep vessel of mercury. If the tube be lowered so as progressively to alter the pressure of the contained gas how will the volume change?

2. State the two laws which govern the transformation of heat into work, and outline the experimental evidence upon which they rest. How is the transformation effected in an ordinary heat engine?

3. In what way does the illumination of a surface depend upon (*a*) the distance from the source, (*b*) the obliquity of the surface to the incident rays.

Prove that if three sources of light simultaneously cast shadows of a rod which are equally dark, then the intensities of the sources are directly as the square of their distances from the screen.

4. Define the refractive index of a body for light. How would you measure with accuracy the refractive index for different colours for glass in the form of a prism?

5. Obtain a formula for the couple on the coil of a suspended coil galvanometer, all necessary data being supposed given.

6. Show by considering three arms, containing batteries and connected in parallel, that the current in any arm is the sum of the currents which would flow in that arm if the three batteries each acted alone the other two being absent.

Section C. CHEMISTRY.

(*Not more than* FOUR *questions to be answered.*)

1. Give a short account of the modern method of preparing oxygen, and explain how you would examine a sample of this gas for (*a*) nitrogen, (*b*) water-vapour.

2. A current of electricity is passed through aqueous solutions of potassium chloride, (*a*) when the electrodes are in compartments separated by a porous septum, (*b*) when the electrodes are in the same cell and the contents are kept well mixed. Describe the changes which occur in each case. Assume the electrodes to be unaffected chemically.

3. Give a full description of the preparation of any two of the oxides of nitrogen and explain the method you would use to determine the percentage composition of either of them.

4. To what substances in solution is the hardness of water usually due? How may the hardness be determined? State what you know of any processes for softening hard waters.

5. What volume of ammonia, measured at standard temperature and pressure, is required to neutralize 50 cubic centimetres of a solution of sulphuric acid containing 49 grams of H_2SO_4 per litre.

(Atomic weights, $H = 1$, $N = 14$, $O = 16$, $S = 32$.)

6. Mention two oxidizing and two reducing agents, and describe experiments with them to illustrate their properties as such agents. Where possible write equations to express the chemical reactions involved.

ELECTRICITY SUPPLY: GENERATION, TRANSMISSION, AND DISTRIBUTION. (First Paper.)

(*Time allowed: 3 hours.*)

(*Not more than* EIGHT *questions to be answered.*)

1. Explain the terms: reactance, power factor, hysteresis, impedance.

2. Describe, with accompanying sketch, some form of synchronizing gear for paralleling alternators.

3. A power station is to be designed to give an effective output of 5,000 kw., with an annual load factor of 25 per cent. State what number of generating sets would be best installed, and their sizes, having due regard to adequate reserve plant. If turbo-alternators are to be employed, state what evaporative duty of boilers would be required; and assuming that surface condensers are used and that the circulating water has an inlet temperature of 56° F., what maximum quantity of water per hour would be required with a 5,000-kw. output.

4. State the advantages and disadvantages of electrically-driven *versus* steam-driven auxiliaries in any average power station.

5. Compare the use of aluminium and copper for a 3-phase transmission line in which spans of not less than 200 yards must be adopted. The conductivity of copper and aluminium being in the ratio of 10 to 6, the tensile strengths as 2·44 to 1, and the relative costs as 7 to 10.

6. Explain what is meant by corona; and state the general effect of high altitudes on high-pressure transmission lines.

7. A load of 100,000 k.v.a. is to be transmitted a distance of 6 miles by underground cables. The pressure to be adopted is 20,000 volts between each of the 3 phases. What would be a reasonable section of cable to employ, and what number of cables should be laid? Describe generally how they should be laid so as to ensure practical immunity from failure of supply.

8. Describe with diagram some practical automatic method of cutting out a high-tension cable in the event of breakdown of insulation.

9. What is the advantage of a 3-wire system as compared with a simple 2-wire distribution?

10. It is proposed to distribute energy by a 3-phase 4-wire system, and the declared pressure at the consumers' terminals is 220 volts. For what pressure should a 3-phase motor be wound, and how should the whole installation of motors and lighting be connected so as to prevent any unbalancing of such a distribution system?

11. Describe some well-known form of house service meter: and state what is the practical limit of accuracy.

Also enumerate some of the faults which may occur in practical working.

12. A consumer requires a supply of 3-phase energy for motors representing a total of 100 h.p. Insurance against failure of supply is an important requirement. State what apparatus the supply authority must fix at the consumer's works to enable the public mains, with a pressure of 6,600 volts between phases, to supply the works motors at a pressure of 380 volts between phases.

ELECTRICITY SUPPLY: GENERATION, TRANSMISSION, AND DISTRIBUTION. (Second Paper.)

(*Time allowed: 3 hours.*)

(*Not more than* EIGHT *questions to be answered.*)

1. A power station equipped with 1,000-kw. steam sets has an annual load factor of 30 per cent. (*a*) What number of units per kw. demand does this load factor represent? (*b*) Given good condensing facilities and normal boiler-house efficiency, what weight of coal of average calorific value (say 13,500 B.Th.U.) should be required per unit generated for reciprocating engines and turbines respectively, taken as a yearly average?

2. A rotary converter is required to work either converting 3-phase energy to continuous current, or in an inverse way converting from continuous-current energy to 3-phase. Describe what auxiliary apparatus must be supplied with the rotary and why it must be used.

3. Prepare a short classified schedule of equipment required, with an approximate estimate of the cost per kw. for the complete equipment, for a power house containing eight 2,500-kw. generators.

4. It is required to check the steam consumption of a turbo-generator situated in place at a public supply station. What apparatus should be used? Describe shortly the observations which should be taken.

5. The input to a 3-phase star-connected line is 10,000 k.v.a., and the initial pressure is 30,000 volts between phases, the power factor being 0·95. The line is designed for a pressure-drop of 10 per cent of the initial pressure. State

(*a*) The current in each conductor,
(*b*) The voltage between each conductor and the neutral point at the receiving end,
(*c*) The total energy received at the end of the line.

6. Describe what is meant by "skin effect."

7. Describe tests which should be made on any generator, for the measurement of (*a*) heating, (*b*) efficiency.

8. What are the effects of a low power factor on the economical running of a power house?

9. A system of 8-ampere continuous-current street arc lamps is to be connected across a 480-volt 3-wire system. Describe, with a diagram, what apparatus should be used to ensure a steady arc. How many lamps should be run in the series; and what number of Board of Trade units would be consumed by the series of lamps in a year of 4,200 lighting hours?

10. What steps should be taken in a tramway (rail return) system to comply with the Board of Trade Regulations as to track leakage?

11. Describe, with diagram, the equipment necessary to complete a service between a public supply main and the consumers' terminals.

12. It is required to ascertain the distribution of light from a street arc lamp. Give a description of the apparatus which should be used and state how the tests should be made.

ELECTRIC LIGHTING AND POWER. (First Paper.)

(*Time allowed: 3 hours.*)

(*Not more than* EIGHT *questions to be answered.*)

1. A station is found to have an annual load factor of 22 per cent—the maximum load is 1,200 kw. What number of units would be sold during the year?

2. Describe, with sketch, an arc lamp, noting the principal parts of the mechanism.

3. Explain the terms power factor and slip.

4. Describe, with diagram, a method of wiring a large building on a 3-wire system, so as to obtain as far as possible a practical balance of load.

5. It is required to record the maximum number of units supplied during any half-hour to an industrial sub-station throughout the year. How can this be done?

6. A rolling mill is to be driven by a reversing 3-phase motor. Describe generally the type of control gear required.

7. A battery is to be used in parallel with a generator to supply a variable traction load. Describe a form of reversible booster which can be used effectively to maintain a steady load on the generator.

8. A portable hand-lamp supplied from a 250-volt circuit has to be used in a wet situation. What means should be adopted to minimize danger from shock arising through faulty insulation or leakage?

9. Describe a form of electrical furnace, with explanatory sketch.

10. A bulk supply is offered at £3 per kw. per annum of maximum demand and 0·33d. per unit metered. This supply has to be converted from 3-phase high-tension to continuous current. The buyer has to provide the necessary converters, which will cost him £5 per kw. to install and on which he allows 10 per cent per annum to cover all capital charges. What will be the resultant cost to the buyer on an annual load factor of 20 per cent, allowing for the average losses in conversion and the supply being taken continuously?

11. Continuous current is supplied to a railway section 2 miles in length on which an average of thirty 200-ton trains run every hour. An average of 65 watt-hours per ton-mile are required to be delivered to the train. State what would be the resultant energy required to be delivered from the high-tension power station after allowance for losses in distribution, rotaries and transmission cables, assuming 3-phase high-tension generation and reasonable proximity of the power house to the track.

12. A tramway system is found on inspection to give 10 volts drop between a distant point on the track rails and an earth-plate at the generating station. Assuming the bonds to be in satisfactory condition and the rail return to be electrically sound, what steps should be taken to bring the drop below the Board of Trade limit of 7 volts?

ELECTRIC LIGHTING AND POWER. (Second Paper.)

(*Time allowed: 3 hours.*)

(*Not more than* EIGHT *questions to be answered.*)

1. An installation of four 10-h.p., two 25-h.p., and one 35-h.p. motors, and 100 40-c.p. metal filament lamps is to be supplied from a public supply 3-phase 4-wire main. The pressure across phases is 380 volts, and the lighting is to be, as near as possible, balanced between phases and the neutral. For what pressure must the lamps be supplied; and what must be the section of each core of the service main, neglecting drop in volts?

2. Describe a method for regulating the speed of an alternating-current variable-speed motor.

3. Describe, with diagram, the connections for either a Ward Leonard or an Ilgner plant, for a winder to be fitted in a mine shaft.

4. Sketch, with time as abscissæ, and volts as ordinates, the discharge curve on a constant resistance of a secondary battery and describe briefly what are the principal requirements to maintain a battery in efficient condition.

5. Describe *one* of the following systems of charging for electrical energy:—

(*a*) Assessment or rateable value.
(*b*) Wright's or Hopkinson's maximum demand.
(*c*) Telephone.
(*d*) Sliding scale.

6. The power factor on a 3-phase public supply system is found to be very low, viz. 0·65: what steps can be taken to improve this?

7. What is a negative booster? Describe its application.

8. State the principal requirements in the design of a railway motor for a suburban service having high schedule speeds and frequent stops.

9. What is the advantage of interpoles in the construction of motors?

10. What is a damping coil? Describe its effect on the design of machines.

11. A single-phase system has been installed in a town where industrial power is afterwards required. Describe how this plant and system can be modified to supply power without waste of capital already expended, and state why the single-phase system must be changed.

12. Describe the Hopkinson method of testing generators or motors.

ELECTRIC TRACTION. (First Paper.)

(*Time allowed: 3 hours.*)

(*Not more than* EIGHT *questions to be answered.*)

1. Define schedule speed, train resistance, draw-bar pull, tractive effort and acceleration as applied to railway or tramway vehicles. Discuss the most convenient unit in which acceleration can be measured for traction purposes.

2. An electric train runs with an average speed of 22 miles per hour. The average distance between station stops is 1 mile, and the train stops 20 seconds at each station. What is the effect on the schedule speed of doubling the average speed and making the stops 30 seconds? What is the resulting average schedule speed?

3. A tramcar usually traverses half a mile between two stopping places in $2\frac{1}{2}$ minutes. It is stopped twice for 5 seconds and 10 seconds respectively to take up passengers. What is the average speed for the normal and for the stopping run?

4. A suburban railway about 20 miles in length has a regular service of stopping trains and occasional non-stop trains, both of the multiple-unit-controlled motor-coach type. Current is supplied to the trains through conductor rails from rotary converter sub-stations supplied from a three-phase generating station at 11,000 volts between conductors. Discuss the separate efficiencies and the overall efficiency you would expect to obtain between the high tension switchboard in the generating station and the motor-driven axles of the train:—

(*a*) for the frequent stopping service,
(*b*) for the infrequent stopping service.

5. In a town with an alternating-current supply of electricity for lighting and a continuous-current supply for a tramway, the tram rails forming the earthed return, the tramway runs for some distance close beside a railway. During Saturday afternoon football traffic it is found that the signalling track circuits on the railway, worked at 2 volts from a battery and using the earth for the return, are interfered with but at no other time. Describe why this is so and suggest the remedy.

6. A tramcar or the motor coach of an electric train is equipped with two continuous-current series motors. Give

a diagram showing first series and then parallel connections of the motors, with the successive cutting out of resistances from the motor circuit, assuming four controller notches with the motors in series and four with the motors in parallel.

7. Show diagrammatically and explain how, in passing from two continuous-current motors connected in series to two continuous-current motors connected in parallel, the change may be made without cutting off the supply from either of the motors.

8. A steam suburban railway service has lost half its traffic due to the competition of a tramway which runs nearly parallel with it for six miles in a densely populated district. The railway passes through a tunnel close to the terminus. Main line and suburban trains are compelled to pass over the same rails in the tunnel. Discuss what hopes there would be of the railway recovering its lost suburban traffic by electrifying the suburban lines.

9. In a conduit tramway the conductor tees (supplied with continuous current) are divided into half-mile sections insulated from each other, and each section is fed separately. It is found that the negative conductor tee frequently goes to earth. Describe the best way of remedying this defect.

10. On a short electric railway with continuous-current motor trains there are never more than three trains on the track at once. Rotary converter sub-stations supply these trains and the daily load factor of the steam generators is 40 per cent. Discuss the effect on this daily load factor of adding batteries (in parallel with the continuous-current sub-station busbars) charged and discharged by an automatic booster. Describe the action of any automatic booster with which you are acquainted suitable for working on a traction load and give a diagram of the field windings.

11. A large industrial town with a non-tidal river flowing through the middle of it has had a tramway system mapped out extending through 100 miles of streets. State whether you would provide one or two generating stations for supplying the 100 miles of tramway route with electrical energy and why.

12. Briefly describe, with sketches, the principle on which any type of surface-contact tramway system works. State the chief difficulties in maintaining a system of tramways worked on the surface-contact system.

ELECTRIC TRACTION. (Second Paper.)

(Time allowed: 3 hours.)

(Not more than EIGHT *questions to be answered.)*

1. For the frequent stopping and starting essential to urban and suburban tramway or railway service what type of continuous-current motor is in general use and why?

2. A tramway some $5\frac{1}{2}$ miles long has 2 miles on the level. Of the remaining $3\frac{1}{2}$ miles there is an up grade to a summit and a down grade, the gradients varying between 1 in 20 and 1 in 100. The power station is at one end of the line. Discuss the best means of making the capital cost of generating station plant and feeders to the track a minimum.

3. A railway proposes to electrify 20 miles of suburban line, on which a service of not less than 4 trains per hour each way is to be run. It is situated in an industrial centre where a power company offers to supply electrical energy at four points in the line at $\frac{1}{2}$d. per kilowatt-hour output from the sub-stations, the agreement to be renewable every 5 years when fresh terms may be negotiated. Should the railway generate for itself or accept the offer?

4. What are the advantages of commutating poles and of forced ventilation for continuous-current railway motors?

5. If the resistance to movement of a vehicle requires an input of 2 watt-hours per ton-mile for every pound per ton resistance when the efficiency of conversion is 100 per cent, state what actual input in kilowatt-hours per mile you would expect to supply to the motors :—

(*a*) For a motor-coach train weighing 100 tons equipped with 600-volt continuous-current motors, when running continuously at 30 miles per hour on the level.

(*b*) For a tramcar weighing 35 tons when running continuously at 12 miles per hour on the level.

6. Give a sketch plan of a car shed for holding 100 electrically equipped tramcars and a repair shop. Indicate the machine tools you would suggest should be provided for all repairs other than car-body repairs.

7. Give a sketch plan of a train shed for holding ten 6-car multiple unit motor-coach electric trains and a repair shop. Indicate the machine tools you would suggest should be provided for all repairs other than car-body repairs.

8. Under what circumstances do you consider it is justifiable to install a conduit system of electric tramways for urban working.

9. The draw-bar pull of an electric locomotive hauling a goods train of 320 tons on the level is 1 ton at 20 miles per hour. What does the pull become on a gradient of 1 in 80 in order to keep the speed the same up the grade as on the level?

10. If in the above example the maximum pull of the locomotive at 20 miles per hour is only 4 tons, to what speed would you expect the train to fall when going up the grade?

11. A double line of tramways with an overhead trolley wire for each line in streets 60 ft. wide changes its direction through a right angle. Poles between the tracks being prohibited, sketch the method you would propose for supporting the trolley wires round the curve.

12. A railway has decided to electrify an existing steam line with 100 miles of single track (of which 30 miles represent sidings) carrying both passenger and goods traffic. It has the option of buying at the same price per kilowatt-hour either single-phase current at a periodicity of 15 at any voltage up to 20,000 or continuous current at 1,500 volts, both delivered at 2 points dividing the line into approximately 3 equal parts. Which supply would you choose and why?

TELEGRAPHY. (First Paper.)

(*Time allowed*: 3 *hours*.)

(*Not more than* EIGHT *questions to be answered*.)

1. A Telegraph Office in which 2,000 primary cells—30 per cent being bichromate cells—are in use is about to be reconstructed and wired for the lighting of the premises by means of incandescent electric lamps (C.C. supply). The room in which the primary batteries referred to are accommodated is required for another purpose; in consequence, it is proposed to remodel completely this part of the telegraph arrangements at this office. Give an outline of the matters you would take into consideration with a view to determining whether the use of primary batteries should be retained or whether some other source of electric energy should be utilized for the purposes of the telegraph circuits at the office in question.

2. A 45-ft. telegraph pole standing in the back-yard of one of a continuous row of cottages—depth of cottages 23 ft., height of ridge of roof above street level 35 ft.—must be replaced by a 60-ft. pole owing to building operations. The back-yard in which the 45-ft. pole stands and in which the 60-ft. pole is to be erected is completely surrounded by buildings, and it is not possible to carry the 60-ft. pole through any of these buildings. The 45-ft. pole stands at a distance of 39 ft. from the kerb of the footpath in front of the row of cottages referred to and against a wall 8 ft. high parallel to the street in which the cottages are situated. Describe and illustrate with sketches the method you would employ to get the 60-ft. pole into the position in which it is to be erected in the back-yard, and state what tools and appliances you would require for the purpose.

3. Compare the relative advantages and disadvantages of aerial and underground conductors for the purpose of telegraph circuits.

4. It is necessary to carry extra high tension electric power wires across an important aerial telegraph line erected on and along a private road. You are instructed to meet the Engineer to the Power Undertaking for the purpose of coming to an agreement with him (with a view to the protection of the telegraph circuits) as to the method of construction to be adopted in the case of the power line at the point where it will cross the telegraph line. Explain, with sketches, the method of construction you consider should be adopted in the case of the power line under the circumstances stated. What (if any) alterations and additions would you consider it desirable to make to the telegraph line in order to obtain the maximum amount of protection for the telegraph circuits?

5. A single core submarine telegraph cable, 163 knots in length, has developed an earth fault; the conductor, however, is not broken. Describe, with diagrams, the method you would adopt to localize this fault.

6. Describe, with diagrams, any central battery duplex system with which you may be acquainted and explain the principle involved in the arrangement described by you.

7. Describe a modern type of polarized sounder and illustrate with diagrams, showing the essential parts of the apparatus. State what advantages are obtained by equipping a telegraph circuit with the type of apparatus described by you in answer to this question.

8. Describe, with diagram, the nature of the arrangement which it is necessary to make in connection with the installation of a repeater on a simplex sounder circuit. What is the object of introducing repeaters on telegraph circuits, and under what circumstances is it usual to employ repeaters?

9. What are the principal classes into which receiving apparatus used in connection with radiotelegraphy may be divided? What are the essential requirements which have to be attended to in the designing of such apparatus?

10. Describe, with diagrams, any type of wireless wave meter with which you may be acquainted, and state the principle upon which its construction depends.

11. Explain, with diagrams, what is meant by (*a*) direct, and what by (*b*) indirect, excitation of a wireless aerial.

12. Describe, with diagrams, a (wireless) magnetic key and state the circumstances under which this type of key is usually employed.

TELEGRAPHY. (Second Paper.)

(*Time allowed*: 3 *hours*.)

(*Not more than* EIGHT *questions to be answered*.)

1. It is proposed to install secondary batteries, maximum discharge current 7 amperes, for telegraph purposes in an important Telegraph Office with long distance quadruplex as well as minor circuits. The telegraph plant is accommodated in a part of a building already wired on the three-wire system, C.C. supply, 480 volts between outers. Give a description of the plant you would install for charging the secondary batteries in question and draw a

diagram of the connections between the several parts of the charging plant and the batteries.

2. What are the methods usually employed for preserving telegraph poles? Describe the details of one of these methods of preservative treatment and state what (if any) advantages it possesses over other methods of preservative treatment which have been adopted for the purpose in question.

3. State the essential details requiring attention in the design of multi-core types of subterranean cable used for telegraph purposes. Give a description of a type of subterranean cable suitable for long distance telegraphy.

4. A Telegraph Office is located in a brick building of substantial construction, rectangular in plan and facing due west—height from ground-level to eaves-gutter 55 ft. Three main aerial telegraph lines converge on the centre in which this office is situated; the directions from which these lines approach the building referred to and the number of wires on each line being as follows:—

(i) Line from due East, carrying 42 wires;
(ii) Line from North making an angle of about 95° with the first-mentioned line and carrying 37 wires; and
(iii) Line from South making an angle of about 120° with the first-mentioned line and carrying 58 wires.

The office is an important testing station. It is not possible to erect ground poles in the immediate neighbourhood of the office. Describe, with sketches, the arrangements you would make and the structure or structures you would provide for the accommodation of the wires on the building in question and how you would carry the wires into the test-room.

5. State briefly what arrangements you would make and what testing equipment you would provide for tracing and localizing faults on the wires at a Telegraph Office into which 65 through and 40 terminal wires enter.

6. The removal of a Telegraph Office, into which 48 telegraph wires are led, has become necessary. The majority of the circuits, *i.e.* 75 per cent of them, are unimportant from the point of view of the volume of traffic carried over them, which amounts, between 8 a.m. and 8 p.m., on an average to 28 telegrams on the least busy and to 37 on the most busy of these minor circuits. The use of telephones in place of telegraph apparatus is not feasible owing to the existence of disturbing power wires, and by reason of the very considerable cost which would be involved in converting the existing single telegraph wires into loops for telephone working. Describe the nature of the installation you would under the circumstances provide in the new office in this case and give your reasons. Illustrate your answer by means of a sketch plan showing the size of room required (with allowance for expansion), general arrangement of instrument tables, position of the apparatus installed, etc.

7. Describe, with diagrams, the principle involved in the construction of the telewriter type of apparatus.

8. Compare the relative suitability of the Wheatstone automatic and Baudot systems for handling rush traffic at periods of abnormal pressure between important centres. Give a brief description of the transmitting apparatus used in connection with one or the other of these systems.

9. What are the fundamental differences between the spark and the arc systems of radiotelegraphy?

10. What is a wireless multiple tuner? What is the principle upon which its construction depends?

11. What is meant by the efficiency of a wireless aerial?

12. Give a description, with diagram, of the Marconi magnetic detector, and state the principle which is involved in its construction.

MANUFACTURE OF ELECTRIC MACHINERY.
(FIRST PAPER.)

(*Time allowed: 3 hours.*)

(*Not more than* EIGHT *questions to be answered.*)

Due consideration will be given to conciseness and neatness of replies.

1. A works requires power from a supply company. Maximum demand 300 kw. The supply available is three-phase at 6,600 volts. Describe with sketches your idea of a suitable sub-station adjoining the works.

2. A firm manufactures a standard line of continuous-current motors. Taking a 10-h.p. armature as an example, describe the manufacturing methods and system of checking you would employ to ensure inter-changeability.

What departures from standard dimensions would you consider reasonable to permit at different parts of the armature?

3. Discuss the mechanical difficulties experienced with the commutators of large continuous-current turbo-generators, and the various methods adopted for overcoming the same.

4. Fig. A is a light former made without joint.

Describe the special tools and methods you would adopt for the manufacture.

5. A factory turns out a large number of repetition articles, such as arc lamps.

Describe what you would consider a suitable system for determining the cost of labour of different processes, and of completed articles; for checking material spoiled, material disappearing, and scrap, and for inspecting

work at different stages of manufacture for throwing out defective work.

6. Various attempts have been made by amateurs to construct a continuous-current dynamo without a commutator. Leaving out of consideration unipolar machines, show from elementary principles why this is not possible.

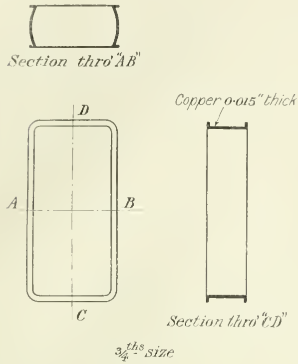


Fig. A.

7. n points are interconnected in such a way that every point is connected to every other point with a resistance r. Any two of the n points, say a and b, may be taken as the terminals of the system or network.

Show that the resistance of the network between a and b is $\frac{2r}{n}$. If a difference of potential be applied between the points a and b, show that all the remaining points of interconnection are at equal potential.

8. A client requires an electric goods hoist, and states that the maximum load is $\frac{3}{4}$ of a ton, and the maximum height to which the goods are to be raised is 150 feet. The supply is to be 500 volts continuous current. A motor and gear are to be placed immediately above the well of the hoist.

If, without further information, you are called upon to give an approximate estimate for motor and gearing, what assumptions would you consider reasonable to make in determining the rating of the motor, and what is the rating of the motor worked out on your assumptions?

In wording your quotation, how would you safeguard yourself in view of your assumptions?

9. A generating station is to be equipped with ten 5,000-kw. three-phase, 6,600-volt machines. Give your ideas of the arrangement of busbars, main switches and protective devices. Assume there are 50 outgoing feeders.

10. Give a diagram of a transformer arrangement for converting from 6,600 volts three-phase to 2,200 volts two-phase. Give the transformer ratios necessary.

11. Describe a reversible booster for use with a large battery, and explain its operation.

12. Give an instance of the circumstances in which resonance may arise at some point of a three-phase supply system, and explain the cause of such resonance.

MANUFACTURE OF ELECTRIC MACHINERY.
(Second Paper.)

(*Time allowed : 3 hours.*)

(*Not more than* EIGHT *questions to be answered.*)

Due consideration will be given to conciseness and neatness of replies.

1. A firm proposes to build a factory for :

Standard Continuous-Current Motors up to 20 h.p.
Or Alternating-Current and Continuous-Current Supply Meters.
Or Metallic Filament Lamps.
Or Lead-covered and other Cables, and Insulated Wires.
Or Secondary Batteries.

The works are to be suitable initially for a turn-over of £50,000 per annum, but are to be capable of extension at a later date.

Choose any one of the above specialities, and sketch briefly your idea of the lay-out of the works, stating the main considerations which would influence you in the choice of site and locality.

State approximately the number of men you would consider necessary for the above output.

2. In fixing the selling price of a manufactured article, how would you take into account :—

Cost of Material, Labour, Foremen's Wages, Heat, Light and Power in Works, Staff Wages, Rent, Rates and Taxes, Directors' Fees, Selling Costs, etc.

Discuss the position if the selling price calculated is above the market price obtainable for the article.

3. Fig. 1 represents a spinning. Sketch out a drilling jig for drilling the various holes shown in the sketch, assuming the articles are put through in lots of 1,000 at a time.

4. A firm proposes to equip a testing-room for testing 30,000 Continuous-Current, 30,000 Single-Phase, and 1,000 Three-Phase Meters per annum.

What instruments would you install as standards and sub-standards?

Give reasons for your selection, and state what general arrangements you would recommend.

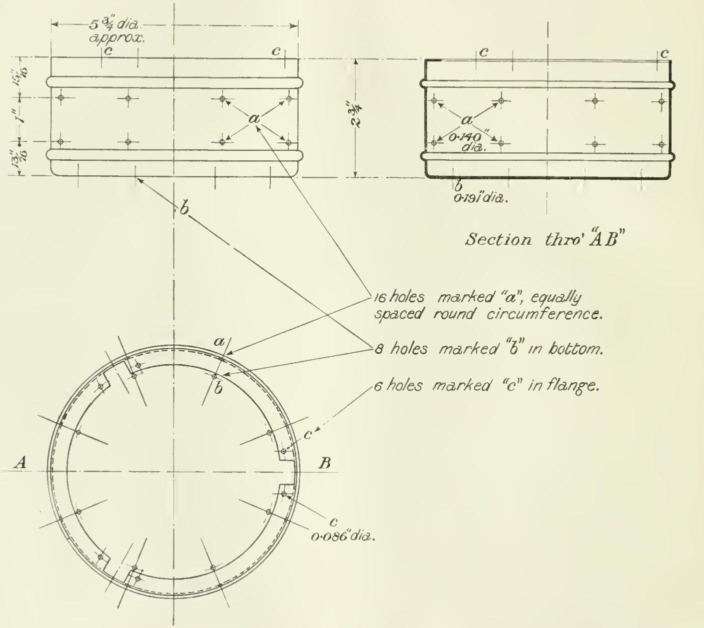


FIG 1.

5. Fig. 2 represents an oil-switch designed for carrying heavy currents. When tested with full-load continuous current it works comparatively cool, but with the same value of alternating current at 50 cycles, the heating is very considerable. Where would you look for the seat of the heating, and what alterations would you make if re-designing?

6. What do you mean by the power factor of a single-phase load?

Distinguish between the cases when the supply E.M.F. is a sine wave, and when it is not.

Can you assign any meaning to the term "Three-Phase Power Factor" when applied to a three-phase load as a whole?

In Fig. 3 a three-phase generator is loaded unequally on lamps between phases. It is found that the currents in the three legs and line wires are not in phase with the terminal voltages, v_1, v_2, v_3. It would appear from this that the power factor of the load taken as a whole was less than unity, although the power factor of each individual portion of the load is undoubtedly unity. How do you account for this?

7. A circular plate weighs 1 pound. 37 discs are punched out of it, these being all equal in size and of the largest size possible. You may assume that the edges of the holes just touch. What is the weight of the scrap?

8. State briefly the chief points dealt with by Mr. Sydney Evershed in his recent paper before the Institution of Electrical Engineers on "The Characteristics of Insulation Resistance."

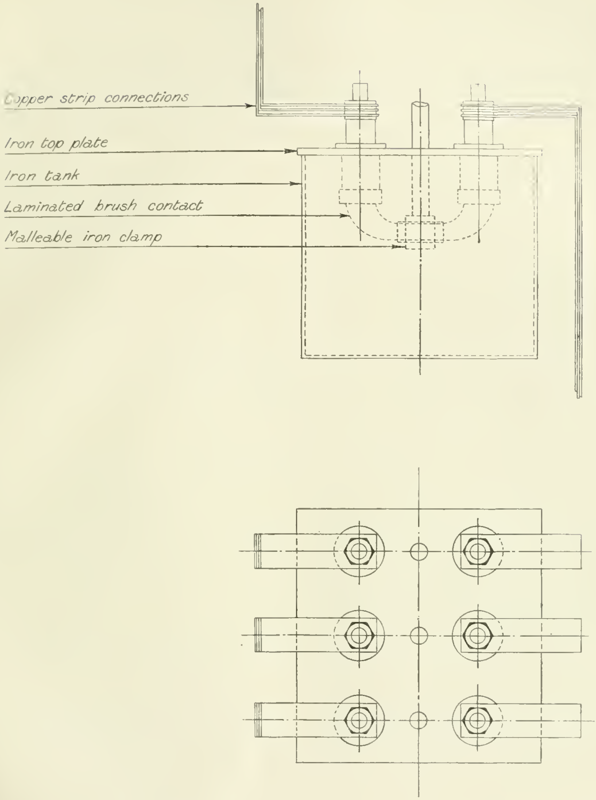


FIG. 2.

9. State the relative advantages of interconnecting a high-tension network throughout, and alternatively, of employing separate and independent feeders, each restricted to the supply of a definite area.

State briefly the methods of protecting feeders, interconnectors, etc., in the two cases.

10. Give arguments for and against earthing the neutral point of a three-phase extra-high-tension supply system, supplying a widely distributed area.

11. Fig. 4 represents a network of resistances as follows :—

a b	4	ohms.
b c	10	,,
c f	12	,,
f a	2	,,
a e	3	,,
e d	3	,,
d c	15	,,

Show that the resistance between *a* and *c* is $5\frac{1}{4}$ ohms, and is independent of the resistance *b d* and *f c*.

12. An electric clock takes $\frac{1}{2}$ watt-hour per annum. Express this in foot-pounds per day of 24 hours.

An electric kettle brings a pint of water from 10° C. to the boiling-point in 7 minutes. 40 per cent of the total heat generated is lost so far as the heating of the water is

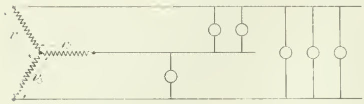


FIG. 3.

concerned. Express the energy supplied to the kettle in watt-hours, and in foot-pounds.

Through a solenoid of copper wire, heavy current is passed for two seconds. The current density is 15,000

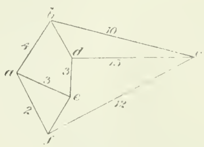


FIG. 4.

amperes per square inch. Determine the outside limit of rise of temperature at any part of the solenoid.

Specific heat of copper = 0·092.
Specific gravity of copper = 8·79.
Resistance of a centimetre cube of copper between opposite faces = $1{\cdot}69 \times 10^{-6}$ ohms.

DESIGN OF ELECTRICAL MACHINERY AND APPARATUS. (FIRST PAPER.)

(*Time allowed : 3 hours.*)

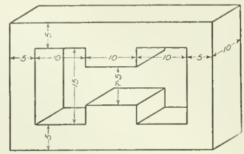
(*Not more than* EIGHT *questions to be answered.*)

1. A 1,000-kw. 3-phase 50-period 6,600-volt generator is to be designed to run at 500 r.p.m. Calculate :—

(*a*) The number of poles.
(*b*) The currents which will flow in the windings with a power factor of 0·8 with both delta and star connections.
(*c*) The true efficiency for the 3-phase winding at full load and 0·8 power factor, from the following data :—

Armature resistance between terminals : 0·6 ohm.
Field resistance : 0·5 ohm.
Field current : 150 amperes at full load 0·8 power factor.
Iron loss : 15 kw.
Friction and windage : 7 kw.

2. Calculate the amount of current required to give an induction of 6,000 C.G.S. lines per square centimetre in the iron for the choke coils shown in the sketch A.



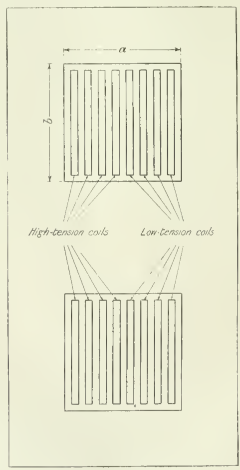
All dimensions are expressed in cm

SKETCH A.

Number of turns, 50.

Magnetizing force required for the iron at specified induction, 1·2 ampere-turns (R.M.S. value) per centimetre length.

The current is at 50 periods.



$a = b$

SKETCH B.

3. What are the principal factors determining the section of a commutating pole and the ampere-turns upon it for a C.C. generator ?

4. Enumerate the different methods of obtaining voltage variation in a rotary converter.

5. Describe the relative advantages and disadvantages of squirrel-cage and slip-ring induction motors.

6. It is desired to design converting plant to operate under an average load of 750 kw. The cost of energy is ½d. per unit. What increase in cost of the plant is justifiable for each 1/10 per cent by which the average efficiency can be improved? Assume figures for interest and depreciation which you consider reasonable.

7. Describe the process of insulating a 500-volt C.C. 3-turn strap-wound armature coil, the section of each conductor being 40 sq. mm. Show cross-section of winding and insulation.

8. Describe the effect on the reactance voltage, of the shell-type transformer shown in sketch B, obtained by altering the proportion of the openings in the iron and by changing the disposition of the coils.

All high-tension coils have the same number of turns.

All low-tension coils have the same number of turns.

9. Describe a method of obtaining phase adjustment and friction compensation in an A.C. watt-hour meter.

10. Describe the construction of any one type of A.C. reverse power relay.

11. In the design of a 10,000-volt oil-switch for handling large amounts of energy, describe the features of design which should be given most careful consideration.

12. Give a diagram of connections for a 3-phase auto-starter, and a diagram of connections for a rotor starter for a 3-phase motor.

DESIGN OF ELECTRICAL MACHINERY AND APPARATUS. (SECOND PAPER.)

(*Time allowed: 3 hours.*)

(*Not more than* EIGHT *questions to be answered.*)

1. Give an armature winding diagram for a 4-pole 3-phase and also for a 2-phase A.C. generator having 24 slots.

2. Why are armature windings sometimes chorded (*i.e.* made with a throw less than full pole pitch) on:—

(*a*) A.C. Generators,
(*b*) C.C. Generators.

3. Show a method of calculating the approximate voltage regulation of a 5,000-k.v.a. 3-phase 10,000-volt A.C. generator at unity and at 0·8 power factor lagging from full to no load, the following information being given:—

No load saturation curve.

Volts.	Field amperes.
8,000	92
10,000	125
12,000	170
14,000	240

On short-circuit 95 amperes is required in the field to give 250 amperes through the armature.

4. Describe the reactance method of obtaining voltage variation of rotary converters and explain the effect upon the power factor.

5. State in a general way the difference between the design of a commutating pole winding for a C.C. generator and for a rotary converter.

6. A transformer of 10-kw. capacity runs 6 hours a day at full load and 5 hours a day at one-half load, while for the remaining time it runs light. What is the difference in yearly running cost between one transformer having at full load 1 per cent iron loss and 2·5 per cent copper loss and one having 1¾ per cent iron loss and 1¾ per cent copper loss, when the cost per unit (kw.-hour) is 1¼d.?

7. Describe the process of insulating an armature coil for a 6,000-volt A.C. generator having 10 turns per coil, each turn having a sectional area of 20 square mm. Give sketch showing cross-section of winding and insulation.

8. Describe what is meant by an auto-transformer (or compensator) and indicate the currents in the windings of a 100-kw. 3-phase star-connected auto-transformer having a ratio of 1,000 to 400 volts.

9. Describe briefly three commercial types of C.C. ammeters, and make a sketch showing the construction of one of these types.

10. Give a simple diagram of connections showing the switchgear you would propose for controlling four 1,000-kw. 6,600-volt generators with direct-coupled exciters and with 8 feeder circuits.

11. Describe the reason for using the resistance between the neutral point of an A.C. generator and earth, and state how this should be designed with reference to heating capacity and ohmic value.

12. Give diagrams of connections and approximate ohmic values of the resistance required for a C.C. motor starter, 10 h.p., 200 volts.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF THE 23RD APRIL, 1914.

Proceedings of the 568th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 23rd April, 1914—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on the 2nd April, 1914, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

Donations to the *Library* were announced as having been received from The Board of Education, D. Clerk, F.R.S., B. Gáti, F. W. Hewitt, A. Home-Morton, A. E. Kennelly, D.Sc., G. A. Puente, W. J. Shaw, A. J. Tanner, and the University of Illinois; to the *Museum* from F. R. C. Rouse; to the *Benevolent Fund* from J. F. Avila, C. V. Drysdale, D.Sc., S. Evershed, J. Gilligan, R. K. Gray, J. S. Highfield, H. Hirst, E. de M. Malan, Sir Henry C. Mance, C.I.E., LL.D., C. C. Paterson, S. G. C. Russell, Sir David Salomons, Bart., S. Sharp, F. Smith, C. P. Sparks, W. C. P. Tapper, A. M. Taylor, and G. W. Warner; and to the *Building Fund* from W. M. Mordey, to whom the thanks of the meeting were duly accorded.

Messrs. E. A. Nash, R. W. Hughman, and F. B. O. Hawes were appointed scrutineers of the ballot for the election of new Members of Council.

A paper by Mr. H. W. Firth, Member, entitled "Electrification of Railways as affected by Traffic Considerations" (see page 609), was read and discussed, and the meeting adjourned at 10 p.m.

INSTITUTION ANNOUNCEMENTS.

CONVERSAZIONE.

The Institution Conversazione will be held at the Natural History Museum, Cromwell-road, South Kensington, S.W., on Thursday, 25th June, 1914, from 9 to 11.30 p.m. Invitation cards will be sent out shortly.

ACCESSIONS TO THE REFERENCE LIBRARY.

ACKERMANN, A. S. E. The utilisation of solar energy. [The Society of Engineers]. 8vo. 68 pp. [*London*], 1914

GRAHAM, J. An elementary treatise on the calculus for engineering students. 4th ed. sm. 8vo. 366 pp. *London*, 1914

HYDRO-ELECTRIC POWER COMMISSION, ONTARIO. Sixth annual report, for year ended Oct. 31st, 1913. 8vo. 338 pp. *Toronto*, 1914

SLIPPY, J. C. Telephone cables. A handbook of the design, construction and maintenance of the telephone cable plant. sm. 8vo. 165 pp. *Pittsburg*, 1913

STEINWEHR, H. v. Silbervoltametrische Messungen. [Sonderabdruck aus der "Zeitschrift für Instrumentenkunde," 1913]. la. 8vo. 25 pp. *Berlin*, 1913

STEPHENSON, E. B. Magnetic properties of Heusler alloys. [University of Illinois, Engineering Experiment Station, Bulletin no. 47]. 8vo. 38 pp. *Urbana, Ill.*, 1910

STEWART, A. Recent developments in the manufacture and use of portable electric tools. [Ipswich Engineering Society, Proceedings, 19th March, 1914]. 8vo. 19 pp. *Ipswich*, 1914

STILLE, C. Les cables télégraphiques et téléphoniques. Traduit par E. Picault et E. Montoriol. 8vo. 360 pp. *Paris*, 1914

WILLIAMS, E. H. The electron theory of magnetism. [University of Illinois, Engineering Experiment Station, Bulletin no. 62]. 8vo. 66 pp. *Urbana, Ill.*, 1912

ZEHME, E. C. Fahrzeuge für elektrische Eisenbahnen. [Die Eisenbahn-Technik der Gegenwart, Bd. 4, Abschnitt E]. la. 8vo. 245 pp. *Wiesbaden*, 1914

THE JOURNAL OF

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DISCUSSION ON

"CURRENT-LIMITING REACTANCES ON LARGE POWER SYSTEMS."*

BIRMINGHAM LOCAL SECTION, 1ST APRIL, 1914.

Mr. R. A. CHATTOCK: The importance of this paper can hardly be overestimated in view of the altered conditions that have now to be met in the design and operation of large power stations. Reliability of supply must be one of the first considerations. The sectionalizing of generating plant is recognized as a prime necessity for this purpose. This process is easy as regards boilers, steam pipes, prime-movers and auxiliaries, but as regards switchgear, reliance has hitherto been placed on the breaking capacity of the switches. It has been evident for some time that under certain conditions of operation even the largest oil switches are damaged when they open, and they even occasionally fail to break the circuit. This would appear to be due to the very large amount of energy that is concentrated on the busbars. In modern generating stations this amount of energy is year by year increasing, and even now the limit of safety in the switchgear would seem to have been reached. The proposal to sectionalize the switchgear by current-limiting reactances, so that the energy to be dealt with by the switches now available may be kept within the limits of easy and safe control, is one that will very largely increase the reliability of the supply. The subject is one that has to be considered from several points of view, depending upon the general lay-out of the generating- and sub-stations to be protected, and the adoption of the best scheme is really a question upon which experts should advise. The chief objections to the use of reactance coils appear to be: (1) The lowering of the power factor; (2) the interference with the regulation of the voltage. A low power factor can of course be met by designing the generators to supply the wattless current required and by providing for greater energy of excitation. In this way payment must be made for the greater reliability of supply, and it is not really exorbitant. The interference with the regulation is, I imagine, a more serious question. The balance of the load between sections must be varying from hour to hour, if not more rapidly, and the constant adjustment of the voltage on the various sections of a large system, required by the insertion of reactance coils between them, must be a very difficult operation. The authors do not say much about this. On page 512 they mention that "the voltage difference can be compensated for by varying the power factors of the synchronous machines." This, I take it, is done by adjustment of the excitation. I should much like to have some further explanation of what is necessary in such a case, and to know whether some special indicators of the conditions obtaining on each section can be provided for the guidance of the attendant. I gather that the authors recommend the division of the reactance in the generator circuits between internal and external reactances, and they seem to indicate that each of these should have a value of about 6 per cent. As I believe that modern turbo-alternators usually have an internal reactance of about 12 per cent, I should like to ask the authors if they would recommend this to be reduced and some of it to be put outside the generator, and whether they consider that 12 per cent total reactance would give sufficient protection. I realize the necessity for having some of this reactance external to the generator in case of a fault developing at the terminals of the machine. The suggested lay-out of a large system shown in Fig. 10 is very instructive. The point raised with reference to the short-circuiting of the busbar reactance coils through the sub-station busbars by feeders connected to different sections of the main busbars could, I suggest, be met by dividing the sub-station busbars and inserting reactance coils between these sections. The possibility of overloading feeder cables by the angular displacement of the voltage, referred to on page 517, is very undesirable and should certainly be guarded against. Mr. Chattock.

Mr. E. P. HOLLIS: Although there has been comparatively little discussion in this country on the uses of reactance coils, objections thereto are beginning to crystallize, and it is now possible to appreciate the views Mr. Hollis.

* Paper by Messrs. K. M. Faye-Hansen and J. S. Peck (see pp. 511 and 655).

Mr. Hollis. of those who do not concur with the advocates of the employment of such coils. These objections are to my mind capable of complete answer, and I propose to concentrate my attention on two of the more important ones rather than to discuss the wider field of the application of these coils. Engineers in charge of the operation of electric power-supply schemes have accepted almost unanimously the benefits that are claimed for reactance, but a few of them have expressed the opinion that special coils for insertion in the generator leads are superfluous, and that the whole of the reactance necessary can be embodied in the machine. It should, however, be realized that external reactance has special functions which cannot be performed by internal reactance: (1) Internal leakage reactance does not protect a generator against complete destruction by a heavy influx of power in the likely contingency of its breaking down. One of the most important functions of the external reactance is to offer such protection. (2) Internal leakage reactance does not protect the end windings of a generator against concentration of potential due to a high-frequency current entering from the line. Special reactance coils are given high insulation in order that they may act as breakwaters against such surges. (3) Once leakage reactance is embodied in the machine its value cannot be varied. Separate reactance coils are susceptible of such adjustment. (4) It is doubtful whether the path of the leakage flux of many generators with large leakage reactance is adequate to enable that path to remain unsaturated on short-circuit. The second objection taken to reactance coils is that of cost. On the debit side of the balance sheet there has to be placed the interest and depreciation on the cost of the reactance, together with any additional sum that should be debited owing to the floor space occupied by these coils; whilst on the credit side are a number of items, the exact value of which it is difficult to appraise, but which are nevertheless of great importance. These are: (1) The insurance of the generators against breakdown by external short-circuits. (2) The insurance of the end-turns against breakdown by high-frequency surges. (3) The insurance of the protection of the windings from complete destruction in the event of an internal breakdown. (4) A saving due to eliminating the need for quickly-operating switchgear. (5) A saving due to the fact that switchgear of a lower rating is necessary. (6) A saving due to eliminating the need for installing elaborate protecting devices. (7) A saving of penalties incurred due to complete or partial breakdown of the generating station.

Dr. Kapp. Dr. G. Kapp: Referring to Fig. 2, I think that where feeder cables are joined by a ring main it would be advisable to have choking coils not only at the near end of each feeder as shown in the paper, but also at the far end. Such a precaution seems to be unnecessary where the feeder is not a cable but an overhead line. In the choking coils shown by the author on the screen there were many turns of wire and an air core a foot or so in diameter. In an overhead feeder there is also an air core in the loop formed by any two wires, but such an air core is several miles long and a few feet wide. The inductance of such a loop would be comparable with and might even exceed many times that of a choking coil with an air core, so that the addition of a special choking coil, at any rate at the far end, would not appear to be necessary. Mention has been made in the discussion of the possibility of omitting the choking coil in the alternator circuit and so constructing the machine that the armature would contain an equivalent amount of inductance. Such a construction is, in my opinion, impracticable. High inductance could not be secured without at the same time getting an unduly large armature demagnetizing effect, so that the regulation of a machine constructed on these lines would be much worse than that of a machine having a moderate amount of armature reaction and an external inductance added. Such addition would, of course, also make the regulation worse, but not to so large an extent. A machine having only a moderately bad regulation could always be made to regulate well by the use of a Tirrill regulator or some equivalent device, so that it would appear that the authors' device of externally applied inductances would be quite compatible with good regulation, provided that each generator were fitted with some kind of automatic regulator taking charge of the exciting current. It should be remembered that such a regulator need not act very quickly, because with the large machines in question changes in load and power factor would take place very slowly.

Mr. Clough. Mr. F. H. Clough: In general I agree with the authors' conclusions. If criticism can be made, I should like to say that these reactance coils take up considerable room and it may be possible to dispense with some of them. Where large power-supply undertakings exist it is essential to take all reasonable means to ensure, first, the continuity of the supply, and, secondly, the protection of the apparatus connected to the system. It is usual, therefore, to divide the plant into sections, so that if a fault occurs it is limited to its own section and the rest of the plant is unaffected. This can readily be done with the boilers, prime-movers, and condensing plant, but there is a difficulty in sectionalizing the busbars, inasmuch as this would mean that the supply areas must also be divided, and in a case of failure of one section of the plant the whole of the area which depends on this section would be without supply. The use of large reactance coils between sections of the busbars may be considered as a semi-isolation. I agree with the authors when they recommend that these should be installed. By properly proportioning them the result of a short-circuit or other breakdown can be limited to the section in which it occurs, but at the same time power may be supplied to any section from the adjacent ones so as to maintain the continuity of supply on it. The use of reactance coils in series with the generators and also in the outgoing feeders protects the apparatus rather than maintains the continuity of supply. The use of reactance coils in series with the generators, however, largely depends on the design of the latter. I think that all small generators can undoubtedly be designed so that they do not need reactance coils to protect them. For large generators this may not always be the case, although here again I feel that they can be dispensed with provided close voltage regulation is not necessary, as mostly happens, since the momentary variation in load carried by a large generator is usually a very small fraction of its rating, and even if comparatively large variations in loads are liable to occur, the voltage can be maintained constant by means of some form of automatic device such as the Tirrill regulator. It has been pointed out that a reactance coil in series with

ugh. the alternator reduces the amount of current that can flow from the neighbouring machines into a fault in its windings. I think, however, that it is unnecessary to install series reactances for this purpose, because if a serious fault occur in the windings of an alternator, it is usually sufficient to damage the machine very seriously even if the latter is running by itself; and therefore any additional flow of current only makes the burn-out more complete. Of course this reactance should not be necessary so far as the other generators are concerned, as these are designed so as to withstand a short-circuit at their terminals. The use of reactance coils in the feeders protects the switches, and if these are not capable of breaking the current that can flow into a feeder when a fault occurs, it may then be necessary to install the reactances. When Fig. 10 in the paper is considered and it is realized that wherever one reactance appears on the diagram there must in fact be three, one for each phase, the large space occupied by them is evident. Inquiry is prompted as to whether they cannot be avoided and whether there are not other means of giving the security and protection necessary. It would seem that so far as the feeder is concerned it should be possible to make use of Merz-Price and Merz-Hunter devices. In the former a current transformer is fitted to each end of a feeder cable and the two transformers are connected in opposition. So long as the cable is sound the current flowing into it must necessarily be equal to the current flowing out of it, and therefore the resultant current in the secondary transformers will be zero. If, however, an "earth" occurs, the balance is destroyed and the cable is disconnected by means of an automatic oil switch. In the latter method each conductor is in two parts and the current transformers are arranged on the assumption that the current will be divided equally between the halves of the conductor. In most of the electricity supply systems in England feeder cables are laid underground, and if they are well made there should be a very remote possibility of a short-circuit between phases. If a fault does occur it usually comes from outside, so that it becomes an "earth" before it can be a short-circuit, and this operates the protective devices and isolates the fault from the system.

hn. Dr. M. L. KAHN: The necessity of using current-limiting reactances in large alternating-current supply systems has been generally recognized; on the other hand it is certainly desirable to restrict the use of this apparatus to a minimum, as, apart from its additional cost, it requires considerable floor space and adds to a system already sufficiently complicated. The authors have stated the different points of the systems in which reactance coils may be desirable, and have set out clearly the advantages and disadvantages of applying them in different positions. As it is undesirable to employ such coils in all the different positions mentioned by the authors, it seems to me that the best compromise that can be effected is to put the reactance coils in the busbars and to use alternators with as high a reactance as possible. The reactance in the alternators themselves will then to a large extent take the place of reactance in the alternator circuits and also in the feeder circuits, as described in the paper. At the same time this has the advantage of reducing the current flowing in the alternator in the case of any breakdown across the terminals, and gives a more efficient machine. In large turbo-alternators the bulk of the losses is made up by iron loss and windage loss. By increasing the reactance the flux in the machine can be decreased with a corresponding decrease in the iron loss. Dr. Kahn. Further, the length of the machine can usually be decreased, and the amount of cooling air required can also be diminished on account of the reduction in the iron loss. As the windage loss depends on the amount of air required, and on the area of the cylindrical surface of the rotor, both of which can be reduced on machines with high reactance, the windage loss of such machine will be lower than the loss in machines with low reactance. The coarser voltage regulation of the machine due to the higher reactance is of minor importance, as machines of the size in question are invariably used in connection with automatic regulators, and the load in stations for which reactance coils are required is usually steady.

Dr. C. C. GARRARD: The first thing that is apparent on Dr. Garrard reading the paper is that by the introduction of reactance coils a considerable increase in the complication of the layout of the generating station is entailed. There is no doubt that there is a great tendency nowadays towards such complexity. If, in addition to these reactance coils, the large banks of high-pressure protective gear, condensers, etc., which are advocated at present are inserted, both the size and the expense of generating stations are bound to increase considerably, a result which may defeat the object in view. Nevertheless continuity of supply for public electricity supply stations is becoming of increasing importance daily; while therefore these added complications should be regarded as evils, even though necessary, their installation must be seriously considered if they should be able to increase the reliability of the supply. On the other hand, if the use of reactance coils can be avoided by improvements in the construction of other apparatus, it seems to me that this should be the path to be followed and that the prevention of trouble due to faultily constructed alternators and switchgear by the introduction of another piece of apparatus would be undesirable. The authors have considered the problem chiefly from two points of view:—(1) Of protecting the alternator from the collapse of its coils. (2) Of saving the oil switches from destruction. As regards these, I should like to ask two questions. Is it not possible to construct turbo-alternators which will withstand "dead" short-circuits? If so, would it not be far better to spend part of the money which would otherwise be expended in the generator reactances in strengthening the windings of the machines so that they can withstand such short-circuits? I also notice that the authors have not dealt to any extent with the question of increasing the internal reactance of the machines rather than that of putting the reactance in the form of a special coil in the generator busbar connections. It seems to me that a solution of the problem of generator protection from this point of view might be attained. The second question that I should like to ask is whether the limit of breaking capacity of oil switches has been reached. That is, given a certain station of a certain short-circuit capacity, cannot oil switches be designed to deal with that short-circuit? If so, it appears to me to be wrong to install smaller switches and endeavour to limit the short-circuit current; we should rather spend the money in installing switches of the proper size. In this connection I think that if reactance coils must be installed in order to safeguard the oil switches, the use of a switch is to be preferred which, in operating, first cuts in

Dr. Garrard. the reactance and then opens the circuit. In this case the reactance coil is normally short-circuited. The first action of the switch (within, say, the first $\frac{1}{8}$ second) is to remove the short-circuit on the reactance coil and the circuit is then opened after a certain time lag has elapsed. With this arrangement the generators are not protected against the very large rush of current that occurs during the first instant of the short-circuit before the armature reaction has had time to assert itself, but as stated before they should be able to withstand this. In my opinion the really important point of view from which to regard this subject is that of the drop in voltage. The reactance coils should be installed with the one object of preventing the pressure falling to such an extent, in the event of a short-circuit, as to cause synchronous machinery to drop out of step. Looked at in this manner it appears that reactance coils in the feeders, as in Fig. 2 in the paper, offer the best solution. As regards Fig. 10, which represents, as I understand it, the use of reactance coils carried out to the full extent, it is mentioned on page 518 that it is "preferable to have each sub-station fed from one section of the busbars." This of course prevents the interconnection of sub-stations, which I am afraid militates against reliability of the supply. I should also be glad if the authors would state whether the oil switches shown in Fig. 10 in series with and in parallel with the busbar reactance coils are automatic switches or are simply hand-operated. As regards the use of iron-clad choke coils, I do not quite understand the necessity of a "straight line" relation between the voltage and the current. Does this expression simply mean that the iron must not get saturated to such an extent in the case of a short-circuit that the permeability falls to practically that of air? The idea has been prevalent that iron could not be used, as, owing to the very short duration of the first rush of current, it did not have time to become magnetized, and therefore an iron choke coil was no better than an air coil. That is to say the initial rush acted as a current of very high frequency, which, as is known, will not magnetize transformer iron of ordinary thickness. If this be correct, it would seem that an iron circuit in any form would be bad, as it would increase the pressure-drop in ordinary working without giving any increased limiting effect in the event of a short-circuit occurring. Perhaps the authors would make this point clear, and state what would be the permeability of the iron under these conditions. I should like some further explanation of the "doubling effect." The experiment mentioned in the footnote on page 511 is not the same as that which would occur on a sudden short-circuit. The initial rush of current obtained by suddenly switching on a choke coil or transformer is due to the polarity of the remanent magnetism of the choke coil or transformer not coinciding with the polarity required, having regard to the particular point in the voltage wave at which contact is made on the switch. I fail to see how this phenomenon can occur in the case of a short-circuit. The question of the use of automatic voltage regulators when busbar reactance coils are used has been raised. If such a regulator be used with each generator, it must be set so that it keeps the voltage of each generator constant and equal to that of the others. That is, the pilot coils of the regulators must be connected to the busbars. If the busbar is sectionalized by reactance coils, I assume that each automatic regulator will have its pilot connected to that section of the busbar to which its own generator is connected. With such an arrangement it would not be possible to operate on the principle shown in Fig. 6, as the automatic regulators would prevent the different busbar sections from being at different potentials.

Mr. H. K. Trechmann: Two speakers have made reference to reactance coils and patent protective systems, whence it might be understood that these perform in some measure the same functions. In my opinion this is not so, as current-limiting reactances are no more able to clear a fault than to prevent one occurring. No existing protective system can succeed in opening an oil switch before the current on a bad fault has reached quite large proportions. Further, it is almost impossible to plan a system of reactances which will successfully limit the fault current in any part of a large network, owing to the unavoidable complexity of the latter and to the large amount of energy which may be fed back from almost any point in it. Reactances are a troublesome complication from the point of view of arrangement, in addition to exhibiting the difficulties dealt with in the paper; *e.g.* the cost of installing a bank of reactance coils into the run of a set of heavy busbars must be very much more than that of the apparatus itself, and the extra space occupied by them is also deserving of attention. The designers of English generating stations have shown in the past an unfortunate tendency to economize the space for switchgear to a very small figure, and the designs of most English oil switches symbolize that tendency. An oil switch for dealing with heavy overloads must be immersed in a large bath of oil, and it must generally possess large clearances and a good head of oil above the break; many otherwise good designs are spoiled by an insignificant quantity of oil being allowed. To illustrate what is possible, it might be stated that an oil switch possessing only a little more than 5 in. of break has been tested with a "dead" short-circuit on 23,100 h.p. of generating plant at 12,000 volts and found to open the circuit successfully; and further, the damage to the contacts, etc., was not sufficient to prevent the switch being easily closed afterwards. Though one cannot say that reactance coils may be entirely dispensed with in the large schemes which are being prepared at the moment, it is certainly not too much to say that if some of the additional space be given to the oil switches, and if suitable designs for the latter be installed, their use can be considerably curtailed in even the largest systems, and the capacity of stations in which they are not used at all can be materially raised.

Mr. F. Forrest: Fig. 10 shows a well-thought-out method of dividing the busbars of a large power station by means of current-limiting reactances, so that every oil switch installed there could be depended upon to open the circuit which it controls under conditions of "dead" short-circuit. I am in hearty agreement with the authors when they state that it is very desirable to feed one sub-station from one section only of the generating station busbars. One reason for this is clearly stated in the paper on page 517, but the authors have not mentioned a second very important reason, which is as follows: Assuming that a sub-station is fed from two sections, and that the sub-station busbars are divided so as to keep the two sections distinct, then it is possible for these two sets of busbars to

Forrest. have a considerable difference in voltage. If this difference in voltage is steady, no particular difficulty arises, but in the event of a sudden transfer of load from one section to another at the generating station, a sudden rise or fall in the voltage of one of the sub-station busbar sections would also result. Since the whole of the sub-station rotary converters are connected in parallel by means of the continuous-current busbars, a sudden rise or fall in voltage on one set of machines to the extent of, say, 5 per cent, would certainly result in something very like a temporary shut-down. The introduction of reactance coils between the feeders and the generating busbars must have a beneficial effect in preventing the high-frequency potential surges set up in the network from unduly straining the insulation of the generators and switchgear. I should be glad if the authors, who are in touch with American practice and experience, can give any information on this point.

Turner. Mr. E. O. TURNER: I should like to obtain some information from the authors with regard to the provision of extra reactance in the generator itself. One speaker pointed out that this may be done by decreasing the total flux of the machine. At the same time, I presume, the number of armature conductors would be proportionately increased, so that although the additional reactance desired is obtained, it is at the expense of an increased armature reaction, with the result that the inherent regulation of the generator becomes worse. If the armature winding is regarded as a choking coil with a partial iron circuit, its reactance can be increased simply by burying the conductors deeper in the slots. Were this done the armature reaction would not be altered, and the regulation, especially at power factors of 0·8 and below, would be much less seriously affected. I should like to ask the authors whether this is feasible in practice, and whether generators are being manufactured having high reactance but normal regulation.

Taylor. Mr. A. M. TAYLOR: With reference to the question as to whether generator reactances should be external or internal, or both, I think that their application to every installation must be considered upon its merits. Fig. 10 in the paper represents very closely the arrangements that are proposed for the new power station at Birmingham. The busbars are here to be divided into five sections, and the output on each section is to be 20,000 kw. The authors say nothing in their paper as to what happens outside the generating station, and I submit that in considering the protection of the generators this is a feature that must on no account be overlooked. If the feeders from the various busbar sections lead to common busbars in different sub-stations, the reactance coils in the generator busbars will be partially or entirely short-circuited thereby; and even if the busbars in the various sub-stations are divided from one another by reactances, the reactance coils in the generator busbars are thereby still partially short-circuited. Again, most electricity supply systems putting down stations of the size indicated will be already in possession of a station of perhaps one-third or one-quarter the size, which has to be connected in parallel with one or more of the sections of the new station. I have reproduced in Fig. A a rough approximation of the conditions that exist in a crowded city like Birmingham, where the whole of the power supply is concentrated within a comparatively small radius of the large generating station, as distinct from the Newcastle system, for example, where I believe the nearest large generating centres are some six miles apart. Allowance has been made in the diagram for the effect of synchronous machinery in the sub-stations. On the assumption that a short-circuit occurs somewhere near the busbars C, the admittance of the whole system into the section C has been worked out, and I find that it would be equal to 32 times the capacity of one busbar section, or about 70,000 amperes. Now if we consider any one of a group of 5,000-kw. generators on one of the main busbar sections, and assume that the short-circuit develops inside the winding and near to the terminals of the generator (which is in fact the position of greatest strain), there would be virtually no reactance between the busbars and the short-circuit if no external reactance were inserted in the generator leads. There would also be a tendency for this current to pass through a short part of the generator winding, and it would result in a force on the conductors

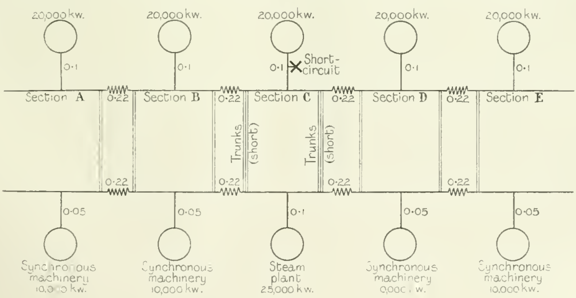


FIG. A.

of the armature equal to 100 times that produced when the generator was tested on short-circuit. The armature conductors would almost certainly be instantly ripped out of their place, and much more serious damage would be done than would occur if the generator were merely short-circuited upon itself without the armature conductors

Mr. Taylor. being shifted. Owing to the instantaneous nature of these forces automatic protective gear would not save the machine. For even if the oil switch opened in $\frac{1}{5}$ second, the danger would have been done in the first quarter-cycle, *i.e.* in 1/20th of the above time. No doubt there are many cases where the conditions which I have indicated above would not occur, and I submit that the only safe way to determine whether or not reactances should be inserted external to the generators is to work out, in the way that I have indicated, the actual admittance of the faulty section and see whether the currents which would pass would be such as to test any part of the machine more severely than would its own short-circuit current, under which it was tested at the time of purchase. It is also interesting to note that if the machine is constructed with, say, an internal reactance of 8 per cent and an external reactance of 8 per cent, and if it is short-circuited on its own internal reactance and will stand up to this, then it will be equally safe from the incoming current from the other generators as it is from its own short-circuit current. Another advantage secured by having an external reactance coil is that the latter may be placed far away from the generator and close to the switchgear, and that it may be so arranged that there are no cable or dividing boxes between the main busbars and the reactance coils. The cable and the dividing boxes are then protected from the busbars as well as the machine itself.

The authors suggest a 50 per cent reactance in the various sections of the main busbars. When this reactance is traversed by one-half of the full load of one section of the busbars, which is a condition that should certainly be made, there will then be a 25 per cent drop of voltage across the reactance even though, as in the case illustrated in Fig. 8, the generator voltages A and B are equal. This difference of potential would exist as far as the feeding centre or sub-station, and considerable difficulties would be introduced unless reactance coils were employed to subdivide the feeding points. Moreover, if the feeders were connected even at a great distance from the station, considerable circulating currents would still pass between them. Although reactances are probably a necessity in the busbars of a 100,000-kw. system there are nevertheless certain serious disadvantages in their use. For instance, the space taken up by them is very considerable, and their effect upon the power factor of the generators is also rather serious. If we had a means for excluding the reactance until the time when it should be really wanted (that is until the short-circuit should occur), it would, I think, be granted that we should have an ideal system. I may here perhaps mention that about two years ago I designed a switch which would perform this function, viz. it would short-circuit a section, or sections, of the reactance coil during normal working, and when the rush of current came it would open and deflect the current through the reactance in something like 1/500 second. I note that Mr. P. M. Lincoln in an article in the *Electric Journal** for December, 1913, suggests the use of ordinary oil switches for the same purpose, and argues that they would operate in time to save the synchronous machinery from falling out of step. He has omitted, however, to point out that such switches would in no wise prevent the tremendous shock that would come upon the generators, which would be virtually connected to a solid busbar without any reactance inserted in it.

The authors' reply to this discussion will be found on page 688.

SCOTTISH LOCAL SECTION, 21ST APRIL, 1914.

Mr. Page. MR. A. PAGE: This paper has come at a most opportune time so far as the staff of the Glasgow Corporation Electricity Department are concerned, as at the present time the design and lay-out of a 100,000-kw. generating station is being considered. It has practically been decided to install reactance coils in the generator circuits and between sections of the busbars; and as there will be step-up transformers on the feeders it will be quite easy to arrange for a 5 per cent reactance in the latter if it is considered desirable to do so. Some influential electrical engineers do not agree that reactance coils are necessary, but while such coils may be dispensed with in the case of a plant giving an entirely alternating-current supply to factories, or even a continuous-current supply to railways, where a supply for such purposes is added to the lighting supply of a large city I consider it to be absolutely essential that steps should be taken to prevent the present risk of breakdown. Reactance coils seem to provide a solution of this problem. There is, however, the difficulty of finding space for the housing of these coils, and as the authors, on pages 517 and 518, practically recommend for a 100,000-kw. installation 50 per cent reactance on the busbars, 10 per cent on the feeder groups, and 5 per cent on the generators, *i.e.* a total of no less than 75,000 k.v.a., the question obviously requires much consideration. These reactance coils will add very greatly to the cost of a station, and for the purpose of an estimate I suppose it would be safe to assume their cost to be £1 per k.v.a. The first consideration must of course be the continuity of the supply, but at the same time we have to be very careful not to increase the capital outlay unduly. I note that there is no reference to harmonics in the paper, and I should like to know whether in that respect these reactances do not introduce a factor which may cause trouble with the insulation. There is also considerable complication in the switchboard connections owing to the presence of reactance coils. Although I am aware that the pressure across a choke coil is in quadrature with the current, and that the authors refer to the wattless current of the reactances, I should be glad of information in regard to the effect of such reactances on the coal bill. Most of our troubles here have been due to feeder breakdowns, and the advantages claimed on page 513 for the use of reactance on feeders seem to promise the elimination of such troubles. It would certainly be of very great advantage if we could keep our sub-stations running when the alternating-current supply is interrupted owing to a fault on a feeder. On page 515 the statement is made that a reasonable size of reactance is one which will give 50 per cent of normal voltage when carrying the full-load current of one busbar section; but in the station that we are considering at Glasgow this would mean a 15,000-k.v.a. reactance, which is clearly out

* P. M. LINCOLN. Protection against short-circuits. *Electric Journal*, vol. 10, p. 1217, 1913.

r. Page. of the question. The vector diagram, Fig. 9, appears quite simple, but with these various voltages and power factors on the machines the lot of the engineer-in-charge will, I imagine, be a most unhappy one. On page 517 reference is made to the case where the same sub-station is supplied from several busbar sections in the power station. This should never be necessary, but it is not so easy to split up the continuous-current network supplied by a group of sub-stations. Some of the sub-stations might be supplied from one section of the power station busbars and others from other sections. In the event of a short-circuit on a high-tension feeder the plant in the power station would probably keep running, but I am afraid that there would be trouble on the continuous-current switchboards in the sub-stations. The table on page 518 is very interesting. From the point of view of maintaining the supply on all the sections, with the exception of the faulty one, combination No. 11 would appear to be the best. On the other hand, No. 5 proves to be surprisingly good on a feeder fault, although there is no busbar reactance. Such an arrangement would prevent the trouble on the sub-station continuous-current busbars to which I have already referred.

cleod. Mr. D. M. Macleod: The first consideration of those responsible should be to secure for the consumers a supply the continuity of which can be depended upon. The introduction of balanced protective gear has had the effect of limiting the disturbances arising from cable or overhead-line faults where these take the form of an earth or short-circuit. Not very many years ago a short-circuit at one point of a system meant the interruption of the supply at several other points far removed from the seat of the trouble, but with the balanced protective devices now available these occurrences are largely things of the past. The balanced protective gear, however, has a very important limitation in so far that it fails to provide any safeguard against busbar troubles, which may include the failure of such apparatus as series transformers, isolating links, and the busbar side of oil circuit-breakers. Where the usefulness of the balanced protective gear ends, that of the current-limiting reactance begins. It should be quite clear that on a supply where balanced protective gear is in use, switchgear and cables may be called upon to transmit very large overloads, and there is a serious danger that the generators themselves may become severely strained due to the heavy fault current with which they have to deal. As an indication of the mechanical forces that large generators have to withstand, I have seen several 5,000-kw. turbo-alternators in which twelve $1\frac{1}{4}$-in. coupling bolts have been permanently distorted as a result of the machine's pulling up on successive short-circuits. The distortion was such that it was found impossible to withdraw the coupling bolts. The authors have dealt very fully with the uses and design of current-limiting reactances, and they have shown fairly clearly in which direction these may be usefully applied. I am not at all sure that the extensive application which they appear to favour is altogether to be commended. A very regrettable feature of many protective devices is their liability to fail in themselves. The failure of series transformers, for instance, is one of the most prolific sources of trouble in power transmission work, and it appears to me that current-limiting reactances would probably share the same weakness and cause as much trouble as what they were designed to avoid. I think it is a common experience with generating plant employing an earthed neutral to find that the majority of faults which arise are due in the first instance to the failure of the insulation of one phase, and I am of opinion that if an efficient current-limiting reactance were inserted in the star-point earth connection the chances of any material damage either to generators, switchgear, or cables, would be very remote. I consider that it is the absence of such a device that is directly responsible for a number of the very serious plant failures which occur from time to time. I certainly would not favour the very free use of reactances which is suggested by the authors, for three reasons: (1) The benefit to be derived would not be commensurate with the expenses involved in their installation; (2) the space that they would require would practically mean the complete reconstruction of existing switchrooms; and (3) their use would interfere with the voltage regulation arising from unequally loaded feeders. On page 512 the authors refer to the case of a short-circuit on a generator and appear to infer that if a reactance were connected in the generator leads the circuit-breaker could be operated in time to disconnect the generator from the busbars and to save the machine from destruction. I think, however, that this is purely illusory, as in the event of a short-circuit on a large generator the draught set up due to the peripheral speed of the rotor would fan the short-circuit into a fierce flame, which would sweep all round the windings and destroy the generating set to such an extent as to involve re-winding. Mr. Macleod.

Mr. Robertson. Mr. J. A. Robertson: This paper is one of the greatest importance to those engaged in the generation and transmission of power on a large scale. It appears to me that the only question is one of balancing the advantages of reactance for each particular case against the disadvantage of increased cost and somewhat greater complication. I was very much interested to learn from Mr. Page that the new power station at Glasgow is to be equipped with reactances as part of the system. I do not agree with Mr. Macleod that reactances should merely be used in the feeders, leaving the generators to take care of themselves. It would appear as if the use of reactances in the feeders, either where duplicate mains are used or on a ring system, would cause complications at the sub-station and interfere with the loading of the feeders. It is rarely the case that a short-circuit on a feeder causes a shut-down of the power station, or even of one generator. The most serious shut-downs which have occurred in recent years have been due to faults on the generator cables or series transformers, and it is here, I think, where some safeguard is called for. The lay-out of the plant could be arranged so that accommodation could be provided for reactances directly under the generator. I have sometimes thought that each generator should have an oil switch placed close to its terminals so as to interrupt the generator current if a fault occurs between the generator and the switchgear, which latter with remote control systems is now being placed farther away. The great improvement that has taken place in generators and switchgear during the last few years must also be taken into account when considering the question of reactances. A modern generator designed with 15 per cent internal reactance will withstand almost any fault that may occur on the system, and with oil-immersed switches capable of dealing with the maximum

Mr. Robertson.

short-circuit current the possibility of a shut-down is very remote, except for defects in the generator or the generator leads. The effect of a short-circuit in the generator itself may be so disastrous that the use of reactance may be justified to limit the amount of damage. The paper is most valuable, and would have been still better if the diagrams had been extended so as to include the sub-station circuits.

Messrs. Faye-Hansen and Peck.

Messrs. K. M. FAYE-HANSEN and J. S. PECK (*in reply to the discussions before the Birmingham and Scottish Local Sections; communicated*): It is interesting to note that practically all of the speakers who have had experience in operating large generating stations, or who expect to operate stations of very large rating in the future, agree that some form of reactance is necessary. Also there is practically unanimity of opinion amongst these engineers that reactances for sectionalizing the busbars are highly desirable. The objections which have been raised to these reactances are as follows:—(*a*) high cost; (*b*) difficulty of finding space in the stations; (*c*) loss in energy; (*d*) necessity for sectionalizing the busbars at sub-stations; (*e*) difficulty of maintaining the proper phase relation between generators supplying different busbar sections.

With regard to the question of cost, this is not a serious item where busbar reactances alone are used, *i.e.* their cost is not a large percentage of the total cost of the station. The difficulty of finding the necessary space for accommodating these coils is a question of much more serious importance, especially in the case of old stations where no provision has been made for them; but in the case of new stations, or where old stations are extended by new buildings, the proper space for these coils can usually be provided without difficulty. The energy losses in the coils may be neglected, as they are quite insignificant.

It seems to be the general opinion that ordinarily there will be little difficulty in supplying one sub-station from one section of the busbars or in sectionalizing the busbars in the sub-stations so that different sections of the busbars in the power station will not be connected to the same busbars in the sub-station, but it will be necessary to operate low-tension circuits in parallel. These low-tension circuits may be supplied with continuous current through rotary converters or with alternating current from step-down transformers so that the reactance coils between sections of the busbars may be short-circuited through the low-tension network. In the case of rotary converters there will be no difficulty if the voltages of the busbar sections in the power station are kept equal, as a phase difference between the alternating voltages would have no influence on the operation at the continuous-current end. In the case of transformer sub-stations supplying an alternating-current network, it would, however, be preferable to lay out the system so that each sub-station is only connected to one busbar section; the different sub-stations supplied from the same busbar section could, of course, be connected to each other by interconnectors, ring mains, etc. Further arrangements will be made in the power station to supply this set of sub-stations from another busbar section in case of trouble in this part of the generating station. We anticipate no difficulty, however, in operating under these conditions, because the resistance of the feeders and the reactance in step-down transformers and rotary converters will introduce a very appreciable impedance into the circuit which parallels the reactance coils in the busbars, and it will only be necessary for the attendant in the generating station to make sure that his feeder cables are not overloaded. This can be easily determined by inspecting the ammeters in the feeder circuit.

There seems to be a misunderstanding on the part of several of the speakers in regard to the operation of generators connected to busbar sections which are separated by reactances; and the difficulties of maintaining the proper phase relations between the different generators under different conditions of load have been mentioned. We would point out, however, that this adjustment of phase relationship is maintained automatically by means of the turbine governors assisted by automatic voltage regulators, which will usually be coupled to each busbar section. The turbine governors ensure that each generator shall deliver its proper share of the load regardless of the distribution of loads upon the busbar section, while the automatic voltage regulators maintain equal voltage on all the busbar sections. Thus the generator voltages are automatically displaced in their phase relation, and the only thing required of the attendant is that he shall watch the ammeter in order to make sure that no generator is overloaded beyond its full value. If he finds that any generator is overloaded, then he must bring in additional generators, or must redistribute his loads, which is no more than he has to do at the present time where all generators are connected to the same busbars.

A large number of the speakers have referred to the desirability of building the generators with very high internal reactance so that no external reactance is required in the generator leads. As pointed out in the paper and the previous discussions, we agree with this view, but with the requirements of regulation still met with it is very difficult in large 2-pole alternators to obtain more than 6 per cent to 10 per cent armature reactance. If the generator will withstand the corresponding current rushes, we do not consider generator reactances essential. It is possible to increase the armature reactance without increasing the armature reaction (and therefore without making the regulation materially worse) by embedding the armature conductors deep into the iron. To obtain any large increase of reactance, however, it will be necessary to embed the conductors very deep, whereby the losses and the cost are considerably increased. The reason for this is that the arrangement must be made such as to prevent oversaturation of the iron inside the winding under short-circuit conditions. This can of course be done by making the slot opening wide enough, but it will generally be found more economical to install external reactance coils than to increase the armature reactance in this way.

It has been pointed out in the discussion that short-circuits usually come on slowly and that discriminating protective gear and quick-acting circuit-breakers should be a sufficient safeguard to the station without the use of reactances. While it is quite true that discriminating protective gear may do much to increase the safety factor of the system, the fact remains that "dead" short-circuits will sometimes occur, and that in such events no switch or relay is sufficiently quick acting to open the circuit-breaker before the rush of current has occurred. Furthermore, no discriminating gear can protect the generator in the event of a misphase, and it is well known that the strain on the generator may be greater in the event of the misphase

than if the generator short-circuited directly across its terminals.

Several speakers have referred to the saving in the cost of switchgear which can be made by installing reactance coils in such a manner as to limit the maximum power that any switch can be called upon to break. On the other hand, it has been argued that if switches of ample capacity are provided there is no need for reactances, and the great simplicity of the design of large oil switches has been dwelt upon by one or two speakers. We find, however, that those manufacturers who have had the greatest amount of experience in building and testing large switches are the most careful in making statements as to what their switches will do before the latter have been tested. There are switches of the reactance type on the market to-day which are guaranteed to control the output of generating plant up to any desired value, but such switches are very expensive and require a large amount of space in the station. As Mr. Wedmore has pointed out, it is commercially impossible to supply every consumer with a circuit-breaker that will deal with a short-circuit with the maximum generator power behind it, and it is the author's opinion that a certain amount of reactance will prove far cheaper and will be safer than any attempt to provide all switches for the maximum breaking capacity of the system.

Reference has been made to the straight-line characteristic of reactance coils. By straight-line characteristic we mean one in which the voltage drop across the coil varies directly with the current through the coil. This is obtained exactly with an air coil, and can be obtained with very close approximation in a coil having iron in the magnetic circuit, provided the iron does not become saturated, and it is therefore necessary to design the coil at such a low induction with normal current that it will not be heavily saturated with the maximum current that will ever pass through it. Thus, if the maximum induction allowable is 25,000, then a 5 per cent reactance would be designed for an induction of 1,250 in the iron part of the circuit, a 10 per cent reactance for 2,500, and a 50 per cent reactance for 12,500. Thus it will be evident that the greater the percentage reactance the greater the advantage of the iron over the air core. It is also worth noting that while in an air-core coil a 10 per cent reactance is approximately double the size of a 5 per cent reactance for the same current, the increase in size is very much less in the case of the coil with an iron core.

It has also been suggested that iron should not be used in a reactance coil as its induction would not respond with sufficient rapidity to sudden changes in current. It should be remembered, however, that changes in current to which the reactance coil should respond are very slow as compared with static surges, and the oscillograph shows that these current changes, while often of great magnitude, are of normal frequency. Therefore, so long as the saturation is not excessive, the choking effect due to the iron is exactly the same as for normal current and frequency.

Reference has also been made to the doubling effect. This is exactly the same phenomenon as is experienced with transformers. There is, however, this difference in the result; the transformer is usually worked at high induction, and when by closing the circuit at the zero point of the voltage wave the induction rises to twice its normal value, a high degree of saturation is attained and the magnetizing current may reach several times normal value. In the air coil the current cannot exceed twice its normal maximum value due to this doubling effect, while with the iron-core reactance the maximum current will not greatly exceed this double value if the iron is worked well below saturation. This is explained clearly in the article in the *Electric Journal* referred to on page 511.

Messrs. Faye-Hansen and Peck.

Mr. Chattock asks how the voltage drop due to reactances in the feeders can be compensated for by varying the power factor of the synchronous machines. This can be done by the attendant in the sub-station, who will vary the field strength of the synchronous machines in such a way as to give constant voltage on the sub-station busbars. In certain cases an automatic voltage regulator could be used for this purpose. Where rotary converters constitute a considerable portion of the load on any sub-station they may be provided with compound windings in order that the power factor will be raised as the load comes on.

Mr. Clough states that "the use of reactance coils in series with the generators and also in the outgoing feeders protects the apparatus rather than maintains the continuity of supply." We were careful, however, to point out that the greatest argument in favour of installing reactance coils in the feeders was the assurance of continuity of supply due to the maintenance of the busbar voltage.

In the Manchester discussion* Mr. Bateman asked how the voltage was divided across the generator and its external reactance, and what effect the external reactance had on the final short-circuit current of the generator. At the instant of short-circuit the voltage will be divided in proportion to the reactances of the generator and the external coil, *i.e.* if the reactance of the generator is 6 per cent and that of the coil is 6 per cent the voltage across the generator will be equal to that across the coil. As the armature reaction of the generator increases, the current will fall until it reaches a constant value. If the synchronous reactance of the generator is 44 per cent, the current will fall to twice the normal value, viz. $100/(44+6)=2$. Without the external coil the current would be 100/44, *i.e.* 2·27 times the normal value.

Mr. Page misunderstands our recommendation in regard to the size of busbar reactances, as it will not be necessary to transmit the full capacity of one busbar section across any busbar reactance. With a busbar section of 30,000 k.v.a. size, and a busbar reactance which will give 50 per cent of normal voltage when carrying full-load current of one busbar section, and assuming that the maximum current which it will be necessary (for any length of time) to transfer across the busbar reactance is 25 per cent of the full-load current of one busbar section, the k.v.a. capacity of the busbar reactance would be 30,000 k.v.a. $\times\ 0{\cdot}5 \times 0{\cdot}25^2 = 930$ k.v.a. This size of busbar reactance cannot be called excessive for power stations of the above size.

We quite agree with Mr. Taylor's statement that each installation must be carefully studied in order to determine whether the use of reactances is desirable, and if so to decide upon the proper lay-out of the system as a whole, including the size and disposition of the reactance coils.

We take this opportunity of mentioning that owing to a misunderstanding we allowed the proof of our reply to the Manchester discussion to be passed for press without being corrected.

* Page 656.

ALTERNATING ELECTROMOTIVE FORCES IN PARALLEL.

THE SUBDIVISION OF THE CURRENT WITH ALTERNATORS AND TRANSFORMERS.

By A. E. Clayton, B.Sc., Associate Member.

(*Paper received 20th March, 1914.*)

Introductory Remarks.

Of recent years a large amount of attention has been given to problems connected with the parallel operation of alternating-current generators, but almost without exception the whole of the papers published on the subject deal with hunting and similar problems.

In the present paper the author discusses the manner in which the current is shared between the machines.

In "Alternating Current Phenomena" Steinmetz deals with the matter, employing the symbolic method, but his solutions are perhaps not very simple. The present author also uses the symbolic method, but he attacks the problem in a different manner from that employed by Steinmetz. The solutions obtained are remarkably simple; in fact, except for the use of the symbolic expression for impedance in the place of the symbol for resistance, the equations obtained might be those for cells working in parallel.

Let us first consider the case of a complex circuit arranged as in Fig. 1, in which there are two harmonic pressures in parallel between the points A and B.

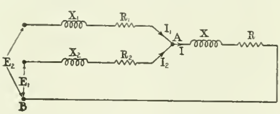


Fig. 1.

Resistance and reactance are included in each branch of the circuit.

Using symbolic expressions, except where otherwise stated, we have—

$$\text{Impedance}\quad Z_1 = R_1 + jX_1,\quad Z_2 = R_2 + jX_2,\quad Z = R + jX,$$

where $j = \sqrt{-1}$.

Let E_1 and I_1 be symbolic values of the pressure and current in branch 1; and E_2 and I_2 be the corresponding values in branch 2. The pressures E_1 and E_2 may be displaced through any angle, but they have the same frequency.

The total current in the main impedance is then equal to the sum of the currents in the two branches, *i.e.*—

$$I = I_1 + I_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The pressure drop due to the impedance in branch 1 is $I_1 Z_1$, and the corresponding pressure drop in the main circuit is $I Z$; whence—

$$E_1 = I_1 Z_1 + I Z,$$
$$= I_1 Z_1 + (I_1 + I_2) Z \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Similarly—

$$E_2 = I_2 Z_2 + (I_1 + I_2) Z \quad . \quad . \quad . \quad . \quad . \quad (3)$$

By solving equations (2) and (3)—

$$I_1 = \frac{E_1 Z_2 + (E_1 - E_2) Z}{Z_1 Z_2 + Z(Z_1 + Z_2)} \quad . \quad . \quad . \quad . \quad (i)$$

$$I_2 = \frac{E_2 Z_1 - (E_1 - E_2) Z}{Z_1 Z_2 + Z(Z_1 + Z_2)} \quad . \quad . \quad . \quad . \quad (ii)$$

and $$I = I_1 + I_2 = \frac{E_1 Z_2 + E_2 Z_1}{Z_1 Z_2 + Z(Z_1 + Z_2)} \quad . \quad . \quad . \quad . \quad . \quad (iii)$$

The potential difference V between the busbars A and B becomes—

$$V = E_1 - I_1 Z_1,$$

and it is also

$$= I Z,$$
$$= \frac{Z(E_1 Z_2 + E_2 Z_1)}{Z_1 Z_2 + Z(Z_1 + Z_2)},$$
$$= \frac{E_1 Z_2 + E_2 Z_1}{Z_1 Z_2/Z + (Z_1 + Z_2)} \quad . \quad . \quad . \quad . \quad . \quad (iv)$$

In the above it is to be noted that E_1 and E_2 are the values (symbolic) of the actual potential differences existing between the terminals of the sources of supply.

In dealing with problems in connection with alternating-current machines in parallel it is customary to divide the machine current into two components, one the load component and the other the synchronizing current.

We have for the current in branch 1—

$$I_1 = \frac{E_1 Z_2}{Z_1 Z_2 + Z(Z_1 + Z_2)} + \frac{(E_1 - E_2) Z}{Z_1 Z_2 + Z(Z_1 + Z_2)},$$

and for that in branch 2—

$$I_2 = \frac{E_2 Z_1}{Z_1 Z_2 + Z(Z_1 + Z_2)} - \frac{(E_1 - E_2) Z}{Z_1 Z_2 + Z(Z_1 + Z_2)}.$$

From the above two expressions it will be seen that the synchronizing or circulating current—

$$I_s = \frac{(E_1 - E_2) Z}{Z_1 Z_2 + Z(Z_1 + Z_2)},$$
$$= \frac{E_1 - E_2}{Z_1 Z_2/Z + (Z_1 + Z_2)} \quad . \quad . \quad . \quad . \quad . \quad (v)$$

and the load components are respectively—

$$I_1' = \frac{E_1 Z_2}{Z_1 Z_2 + Z(Z_1 + Z_2)} \text{ and } I_2' = \frac{E_2 Z_1}{Z_1 Z_2 + Z(Z_1 + Z_2)} \quad (vi)$$

The total load current $= I_1' + I_2'$.

From equations (i) to (vi) the symbolic expressions for the various currents, etc., are obtained; these symbolic values give at once both the effective value and the correct phase relationship of the various terms.

To illustrate the above method the author proposes to work out two examples, one with pressures in phase but of different values, the other with equal pressures having a phase displacement.

CASE 1.—*Pressures in phase.*

Effective value of $E_1 = 100$ volts, and of $E_2 = 90$ volts. Take the reference vector as being in phase with E_1.

Then the symbolic value of $E_1 = 100 + j\,0$,
$E_2 = 90 + j\,0$.

Take the case with $R_1 = R_2 = 0{\cdot}1$ ohm,
$X_1 = X_2 = 0{\cdot}8$ ohm,
$R = 2{\cdot}9$ ohms; $X = 1{\cdot}2$ ohm.

We have $Z_1 = Z_2 = R_1 + jX_1 = 0{\cdot}1 + 0{\cdot}8j$,
$Z = R + jX = 2{\cdot}9 + 1{\cdot}2j$.

$$\frac{1}{Z_1 Z_2 + Z(Z_1 + Z_2)} = \frac{1}{(0{\cdot}1 + 0{\cdot}8j)^2 + (2{\cdot}9 + 1{\cdot}2j)(0{\cdot}2 + 1{\cdot}6j)}$$
$$= \frac{1}{5{\cdot}04j - 1{\cdot}93} = -(0{\cdot}173j + 0{\cdot}067).$$
$$E_1 Z_2 = 100(0{\cdot}1 + 0{\cdot}8j) = 10 + 80j,$$
$$E_2 Z_1 = 90(0{\cdot}1 + 0{\cdot}8j) = 9 + 72j,$$
$$(E_1 - E_2)Z = (100 - 90)(2{\cdot}9 + 1{\cdot}2j) = 29 + 12j.$$

Whence—

$$I_1 = [(10 + 80j) + (29 + 12j)] \times [-(0{\cdot}173j + 0{\cdot}067)] = 13{\cdot}3 - 12{\cdot}9j,$$
$$I_2 = [(10 + 80j) - (29 + 12j)] \times [-(0{\cdot}173j + 0{\cdot}067)] = 11{\cdot}7 - 0{\cdot}5j,$$
$$I = I_1 + I_2 = 25 - 13{\cdot}4j,$$
$$I_s = [(29 + 12j)] \times [-(0{\cdot}173j + 0{\cdot}067)] = 0{\cdot}16 - 5{\cdot}8j,$$
$$V = 100 - (13{\cdot}3 - 12{\cdot}9j)(0{\cdot}1 + 0{\cdot}8j) = 88{\cdot}1 - 9{\cdot}3j.$$

In the above expressions the real terms denote the components in phase with the vector of reference, and the imaginary terms the components at right angles to the vector of reference. The minus sign indicates an angle of lag.

The effective values can readily be obtained from the two components as shown in Table I.

As a check on the above the main impedance has a real value of $\sqrt{2{\cdot}9^2 + 1{\cdot}2^2} = 3{\cdot}14$ ohms.

Hence the main current $= 89{\cdot}1/3{\cdot}14 = 28{\cdot}4$ amperes, and it lags behind the busbar potential difference by an angle $= \tan^{-1} 1{\cdot}2/2{\cdot}9 = 22{\cdot}5$ degrees.

From the table above we obtain $28{\cdot}3 - 6 = 22{\cdot}3$ degrees.

The above example illustrates the well-known fact that the wattless current is obtained chiefly from the source having the larger E.M.F. The watt current is divided practically in the ratio of the E.M.F.'s, so that the power taken from the two sources is roughly proportional to the squares of their E.M.F.'s. The synchronizing current is practically wattless.

CASE 2.—*Pressures equal in magnitude but having a phase displacement.*

The reference axis will be taken in phase with E_1, and the following values will be assumed:—

$$E_1 = 100 + j\,0,$$
$$E_2 = 100(\cos\alpha - j\sin\alpha).$$

Take the case when $\alpha = 10°$; $E_2 = 98{\cdot}5 - 17{\cdot}5j$; $R_1 = 0{\cdot}1$; $X_1 = 0{\cdot}9$; $R_2 = 0{\cdot}2$; $X_2 = 1{\cdot}8$; $R = 8$; $X = 6$.

$$\frac{1}{Z_1 Z_2 + Z(Z_1 + Z_2)} = \frac{1}{(1 + 0{\cdot}9j)(0{\cdot}2 + 1{\cdot}8j) + (8 + 6j)(0{\cdot}3 + 2{\cdot}7j)}$$
$$= -(0{\cdot}0192 + 0{\cdot}0296j).$$
$$E_1 Z_2 = 100(0{\cdot}2 + 1{\cdot}8j) = 20 + 180j,$$
$$E_2 Z_1 = (98{\cdot}5 - 17{\cdot}5j)(0{\cdot}1 + 0{\cdot}9j) = 256 + 86{\cdot}8j,$$
$$(E_1 - E_2)Z = (1{\cdot}5 + 17{\cdot}5j)(8 + 6j) = -93 + 149j,$$

Whence $I_1 = -(-73 + 329j)(0{\cdot}0192 + 0{\cdot}0296j) = 11{\cdot}13 - 4{\cdot}15j,$
$$I_2 = -(118{\cdot}6 - 62{\cdot}2j)(0{\cdot}0192 + 0{\cdot}0296j) = -4{\cdot}1 - 2{\cdot}3j,$$
$$I = 7{\cdot}05 - 6{\cdot}45j,$$
$$I_s = -(-93 + 149j)(0{\cdot}0192 + 0{\cdot}0296j) = 6{\cdot}2 - 0{\cdot}1j,$$
$$V = 100 - (11{\cdot}15 - 4{\cdot}15j)(0{\cdot}1 + 0{\cdot}9j), = 95{\cdot}2 - 9{\cdot}6j.$$

TABLE I.

		Symbolic Value	Effective Value	Angle of Lag
E_1	Pressure	$100 + 0j$	100	0
	Current	$13{\cdot}3 - 12{\cdot}9j$	$\sqrt{13{\cdot}3^2 + 12{\cdot}9^2} = 18{\cdot}5$	$\tan^{-1} 12{\cdot}85/13{\cdot}3 = 44°$
	Power	...	$100 \times 13{\cdot}3 = 1330$	...
E_2	Pressure	$90 + 0j$	90	0
	Current	$11{\cdot}7 - 0{\cdot}5j$	$\sqrt{11{\cdot}7^2 + 0{\cdot}5^2} = 11{\cdot}7$	$\tan^{-1} 0{\cdot}582/11{\cdot}7 = 2{\cdot}5$
	Power	...	$90 \times 11{\cdot}7 = 1050$	...
Busbar p.d.		$88{\cdot}4 - 9{\cdot}3j$	$\sqrt{88{\cdot}4^2 + 9{\cdot}3^2} = 89{\cdot}1$	$\tan^{-1} 9{\cdot}3/88{\cdot}4 = 6{\cdot}0°$
Synchronizing current		$0{\cdot}16 - 5{\cdot}8j$	$\sqrt{0{\cdot}16^2 + 5{\cdot}8^2} = 5{\cdot}8$	$\tan^{-1} 6{\cdot}15/0{\cdot}8 = 82{\cdot}5°$
Main current		$25 - 13{\cdot}4j$	$\sqrt{25^2 + 13{\cdot}4^2} = 28{\cdot}4$	$\tan^{-1} 13{\cdot}4/25 = 28{\cdot}3°$

The effective values are given in Table II.

TABLE II.

		Symbolic Value	Effective Value	Angle of Lag behind E_1
E_1	Pressure	$100 + 0j$	100	0
	Current	$11{\cdot}13 - 4{\cdot}15j$	11·8	20·3°
	Power	...	1,113	...
E_2	Pressure	$98{\cdot}5 - 17{\cdot}5j$	100	10°
	Current	$-4{\cdot}1 - 2{\cdot}3j$	4·7	151·5°
	Power	...	−365	...
Busbar p.d. ...		$95{\cdot}2 - 9{\cdot}6j$	95·5	5·8°
Synchronizing current ...		$6{\cdot}2 - 0{\cdot}1j$	6·2	1°
Main current ...		$7{\cdot}05 - 6{\cdot}45j$	9·55	42·4°

As a check we have :—

The main impedance is $\sqrt{6^2 + 8^2} = 10$ ohms, and the effective current $95{\cdot}5/10 = 9{\cdot}55$ amps. The angle of lag behind the busbar potential difference $= 36{\cdot}9$ degrees, compared with the above value of $42{\cdot}4 - 5{\cdot}8 = 36{\cdot}6$ degrees.

The effect of the phase displacement between the E.M.F.'s is shown clearly; the source of the lagging E.M.F. receives energy at the mean rate of 365 watts; the component and the first term the load component. Thus the load component—

$$I_1' = \frac{E_1}{Z_1 + Z(Z_1 + Z_2)/Z_2}.$$

The equivalent impedance which gives rise to the load component is thus $Z_1 + Z(Z_1 + Z_2)/Z_2$. Z_1 is the internal impedance of the branch; thus the equivalent impedance offered by the main load Z is $Z(Z_1 + Z_2)/Z_2$, and the admittance is $Y Y_1/(Y_1 + Y_2)$, where $Y = 1/Z$, etc. Thus the equivalent load admittances for the two sources of supply are obtained by dividing the total load admittance in the ratio of their admittances, *i.e.* in the inverse ratio of their impedances. It will be noted that the value of the load component I_1' is quite independent of the value of the E.M.F. of the second source.

2. *Synchronizing current.*

$$I_s = \frac{(E_1 - E_2)Z}{Z_1 Z_2 + Z(Z_1 + Z_2)},$$

$$= \frac{E_1 - E_2}{Z_1 Z_2/Z + (Z_1 + Z_2)}.$$

The equivalent impedance of the path of the synchronizing current is thus $Z_1 Z_2/Z + (Z_1 + Z_2)$.

The last term is the actual series impedance of the two branches. The term $Z_1 Z_2/Z$ takes account of the effect of the load components of the currents. When the load is light, Z is large and the equivalent impedance to the synchronizing current $\doteqdot Z_1 + Z_2$. On heavy loads Z is small and the term $Z_1 Z_2/Z$ must be included. When $Z = 0$, the synchronizing current also $= 0$.

Since the effect of the synchronizing currents depends upon their magnitude and their phase displacement, it is obvious that the restoring power developed will depend upon both the magnitude and the nature of the load.

TABLE III.

$\cos\phi$	Z	I_1	I_2	I_s	I
0	$2{\cdot}5j$	$27{\cdot}1 - 86{\cdot}1j$	$-35{\cdot}2 - 86{\cdot}9j$	$26{\cdot}8 + 0{\cdot}43j$	$-8{\cdot}1 - 173j$
0·4	$1 + 2{\cdot}29j$	$57{\cdot}3 - 82j$	$-5{\cdot}2 - 83{\cdot}4j$	$27{\cdot}2 - 0{\cdot}8j$	$52{\cdot}1 - 165{\cdot}4j$
0·6	$1{\cdot}5 + 2j$	$74{\cdot}6 - 76{\cdot}3j$	$12{\cdot}9 - 78j$	$27{\cdot}6 - 1{\cdot}52j$	$86{\cdot}5 - 154{\cdot}3j$
0·8	$2 + 1{\cdot}5j$	$94 - 64{\cdot}6j$	$31 - 66j$	$28{\cdot}4 - 2{\cdot}6j$	$125 - 130{\cdot}6j$
1·0	$2{\cdot}5$	$127 - 19{\cdot}7j$	$65 - 21j$	$30{\cdot}5 - 4{\cdot}2j$	$192 - 40{\cdot}7j$
0·8	$2 - 1{\cdot}5j$	$129 + 48{\cdot}2j$	$66{\cdot}5 + 46{\cdot}6j$	$34{\cdot}2 - 4j$	$196{\cdot}2 + 94{\cdot}8j$
0·6	$1{\cdot}5 - 2j$	$113{\cdot}5 + 79{\cdot}7j$	$50{\cdot}8 + 77{\cdot}9j$	$35{\cdot}5 - 3j$	$164{\cdot}3 + 157{\cdot}6j$
0·4	$1 - 2{\cdot}29j$	$92{\cdot}7 + 102{\cdot}7j$	$32{\cdot}2 + 97j$	$36{\cdot}2 - 1{\cdot}8j$	$124{\cdot}9 + 204{\cdot}3j$
0	$-2{\cdot}5j$	$37{\cdot}8 + 120{\cdot}4j$	$-24{\cdot}7 + 117{\cdot}6j$	$37{\cdot}2 - 1{\cdot}4j$	$13{\cdot}5 + 238j$

external circuit at the rate of $(9{\cdot}55)^2 \times 8 = 730$ watts; the ohmic losses for the two sources at the rate of $(11{\cdot}15)^2 \times 0{\cdot}1 + (4{\cdot}7)^2 \times 0{\cdot}2 = 17$ watts. The mean power taken from the source of leading E.M.F. thus sums up to 1,112 watts. The synchronizing current is now practically at unity power factor so far as E_1 is concerned.

Let us now consider more fully the formulæ that we have obtained.

1. *Current.*

The current in branch 1 is given by—

$$I_1 = \frac{E_1 Z_2}{Z_1 Z_2 + Z(Z_1 + Z_2)} + \frac{(E_1 - E_2)Z}{Z_1 Z_2 + Z(Z_1 - Z_2)}.$$

The second term gives the value of the synchronizing

3. *Main current.*

$$I = \frac{E_1 Z_2}{Z_1 Z_2 + Z(Z_1 + Z_2)} + \frac{E_2 Z_1}{Z_1 Z_2 + Z(Z_1 + Z_2)},$$

$$= \frac{E_1}{Z_1 + Z(Z_1 + Z_2)/Z_2} + \frac{E_2}{Z_2 + Z(Z_1 + Z_2)/Z_1}.$$

The total current in the external circuit is readily obtained by adding together the load components of the currents from the two sources.

EFFECT OF THE EXTERNAL ANGLE OF LAG.

In order to show the effect of the nature of the load the following case has been worked out—

$$E_1 = 500\,;\ E_2 = 500 - 50j.$$
$$Z_1 = Z_2 = 0{\cdot}02 + 0{\cdot}8j.$$

External impedance is constant and $= 2{\cdot}5$ ohms, but the angle of lag varies from $+90°$ to $-90°$, *i.e.*—

$$\begin{aligned} Z &= 2{\cdot}5j && \text{lag of } 90°,\ \cos\phi = 0, \\ &= 1 + 2{\cdot}2j && \cos\phi = 0{\cdot}4, \\ &= 1{\cdot}5 + 2j && \cos\phi = 0{\cdot}6, \\ &= 2 + 1{\cdot}5j && \cos\phi = 0{\cdot}8, \\ &= 2{\cdot}5 && \cos\phi = 1{\cdot}0, \\ &= 2 - 1{\cdot}5j && \cos\phi = 0{\cdot}8 \text{ leading}, \\ &\quad \text{etc.} \end{aligned}$$

The results are shown in tabular form in Tables III, IV, and V.

TABLE IV.—*Effective Values.*

	Main Circuit		Branch 1		Branch 2	
Cos φ	Volts	Amperes	Amperes	Watts × 1,000	Amperes	Watts × 1,000
0	432	173	90·5	13·55	94	— 13·25
0·4	432	173	99·5	28·65	83·5	— 1·57
0·6	442	177	107	37·3	79	10·35
0·8	452	181	114	47·0	73	18·8
1·0	488	196·5	129	63·75	68	33·6
0·8	545	218	138·5	64·85	81	30·9
0·6	570	228	139	56·75	93	21·5
0·4	583	237	138	46·35	102	11·25
0	585	238	126	18·9	120	— 18·23

TABLE V.—*Synchronizing Current, etc.*

Main Current		Synchronizing Current	
Cos φ	Amperes	Watt Component Amperes	Syn. Watts × 1,000
0	173	26·8	13·4
0·4	173	27·2	13·6
0·6	177	27·6	13·8
0·8	181	28·4	14·2
1·0	196·5	30·5	15·3
0·8	218	34·2	17·1
0·6	228	35·5	17·8
0·4	237	36·2	18·1
0	238	37·2	18·6

The curves (Fig. 2) show the manner in which the currents, etc., depend upon the power factor of the load.

It will be noted that the effective values of the currents in the two branches are widely different except at low power factors. The influence of the nature of the load upon the synchronizing watts is clearly shown. For a load current of 200 amperes the synchronizing watts are from 30 to 40 per cent greater at zero power factor leading than at zero power factor lagging.

EXPERIMENTAL RESULTS.

In order to check the above calculations a series of experiments was carried out by the author. In the first series of experiments 100-volt 50-cycle mains were connected in parallel with the secondary of a 1 : 1 transformer fed by the same mains, impedance being included in the circuit as is shown in Fig. 3. The main impedance was obtained from the readings of the main ammeter, voltmeter, and wattmeter. The impedances of the branches B C and D C were obtained by means of a voltmeter and an ammeter, and their resistances by similar means with

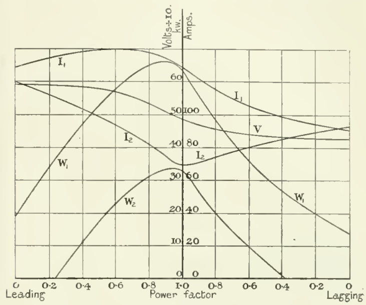


FIG. 2.

continuous currents. The reactances in the paths B C and D C consisted of choking coils having iron cores, but the error due to omitting the iron losses in the cores is insignificant. The instruments used were ordinary switchboard instruments, and the agreement between the test figures and the calculated figures was exceedingly good.

In order to obtain a phase displacement between the

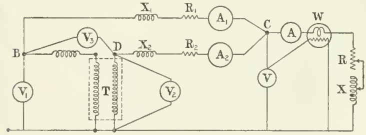


FIG. 3.

pressures, a small choking coil was introduced in the primary circuit of the transformer. This produced a secondary E.M.F. smaller than and displaced from the potential difference between the mains.

To obtain the value of the phase displacement, readings of the pressures E_1, E_2, and $E_1 - E_2$, were obtained, and the triangle of voltages was constructed (see Fig. 4).

A few only of the test results are shown in Table VI. It will be noted that the difference between the observed and the calculated figures is insignificant.

In the second series of experiments a double-current generator with 6 slip-rings for 1-, 2-, or 3-phase current was used.

TABLE VI.—*Experimental Results.*

	Test	A	B	C
Experimental Readings	Pressure, E_1 volts	102	102	97
	„ E_2 „	98	99	89
	„ $E_1 - E_2$ „	4	3	22
	Current, I_1 amperes	16·6	12·9	14
	„ I_2 „	11·6	8·9	3 (?)
	„ I_3 „	27·5	21·8	16·5
	Potential difference, V volts	86·5	78	86·5
	Power, W watts	2,415	1,350	1,430
Calculated Symbolic Values	$[E_1]$	102	102	97
	$[E_2]$	98	99	86 − 21·5 *j*
	$[Z]$	2·97 + 0·61 *j*	2·83 + 2·18 *j*	5·15
	$[Z_1]$	0·21 + 2·12 *j*	0·21 + 2·12 *j*	0·21 + 2·12 *j*
	$[Z_2]$	0·22 + 2·9 *j*	0·22 + 2·9 *j*	0·22 + 2·9 *j*
	$[I_1]$	13·1 − 9·7 *j*	8·0 − 10·3 *j*	13·2 − 4·6 *j*
	$[I_2]$	9·5 − 6 *j*	7·3 − 6·7 *j*	2·3 − 0·6 *j*
	$[I]$	22·6 − 15·7 *j*	15·3 − 17·0 *j*	15·5 − 5·2 *j*
Calculated R.M.S. Values	I_1	16·3	13·1	13·8
	I_2	11·3	9·7	2·4
	I	27·5	22·8	16·3

TABLE VII.—*Experimental Results.*

	Test	D	E	F	G	H
Observed Readings	Pressure, E_1 volts	98·5	98·5	96	89·5	90·5
	„ E_2 „	70	74·5	71	67	66
	„ $[E_1 - E_2]$ „	73·5	70	69	68·5	68·5
	Current, I_1 amperes	10·2	11·9	11·0	11·9	9·9
	„ I_2 „	10·2	8·4	12·3	16·1	17·4
	„ I „	10	12	15	21	20·5
	Potential difference, V volts	58	53	47	40	49
	Power, W watts	355	40 (?)	480	690	990
	Impedance drop, V_{Z_1} volts	43	51	46·5	50	41
	„ V_{Z_2} „	39	33	44	53	57
Calculated Symbolic Values	$[E_1]$	98·5	98·5	96	89·5	90·5
	$[E_2]$	46·5 + 42 *j*	52·5 + 52·5 *j*	49·5 + 50·5 *j*	43·5 + 51 *j*	43 + 49 *j*
	$[Z]$	3·7 + 4·5 *j*	0·3 + 4·4 *j*	2·13 + 2·28 *j*	1·56 + 1·06 *j*	2·35 + 0·33 *j*
	$[Z_1]$	0·18 + 4·2 *j*	0·18 + 4·4 *j*	0·2 + 4·2 *j*	0·18 + 4·2 *j*	0·18 + 4·1 *j*
	$[Z_2]$	0·36 + 3·8 *j*	0·36 + 3·9 *j*	0·36 + 3·6 *j*	0·36 + 3·3 *j*	0·36 + 3·7 *j*
	$[I_1]$	− 2·3 − 9·0 *j*	− 3·9 − 10·9 *j*	− 0·7 − 11·1 *j*	0·8 − 12 *j*	2·2 − 9·5 *j*
	$[I_2]$	10·0 + 2·7 *j*	8·7	12·4 − 0·8 *j*	15·8 − 0·9 *j*	17 + 1·9 *j*
	$[V]$	7·7 − 6·3 *j*	4·8 − 10·9 *j*	11·7 − 10·3 *j*	16·6 − 12·9 *j*	19·2 − 7·6 *j*
	$[V]$	57·5 + 13·5 *j*	49·5 − 18·5 *j*	48 + 5 *j*	39 − 1·5 *j*	50 − 7 *j*
Calculated R.M.S. Values	I_1	9·4	11·7	11·1	12·0	9·8
	I_2	10·2	8·7	12·4	15·9	17
	I	10	11·9	15·5	20·8	20·7
	V	59	53	48	39	50
	W	358	36	482	665	1,010

The E.M.F. between slip-rings 1 and 2 is obviously displaced by 15° from that between slip-rings 1 and 3, and by 90° from that between slip-rings 1 and 4. The connections were such that the currents were as shown in

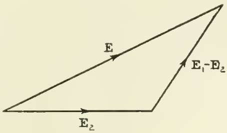


FIG. 4.

Fig. 4, various combinations being used. The resistances of the branches BC and DC were measured by means of continuous currents, and the iron losses in the choking coils were neglected.

Table VII gives a few of the results.

Alternators in Parallel.

With alternating-current generators we have to deal with the magnetizing effects of the armature currents as well as with the true armature self-induction. It has been shown elsewhere that the effect of armature reaction is equivalent to an added reactance, so that the whole effect of the armature currents may be regarded as due to an equivalent impedance. The equivalent reactance, however, is not constant, but depends upon the degree of saturation of the magnetic circuit. With no saturation the equivalent coefficient of self-induction $= L_r + L_a'$, where L_r is the real coefficient of self-induction, and L_a' is the coefficient of self-induction which is equivalent to the armature reaction.

The author has shown elsewhere* that the effect of

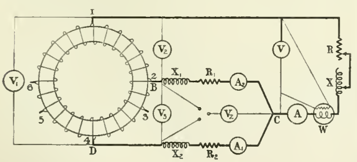


FIG. 5.

saturation is to diminish the effect of the armature reaction according to the saturation constant. This saturation constant S is the ratio $\dfrac{\text{actual slope of characteristic}}{\text{initial slope of characteristic}}$.

The effect of armature reaction is thus equivalent to a self-induction of $L_a = S\,L_a'$. The value here taken for the alternator reactance is therefore the equivalent value, *i.e.* $2\,\pi f(L_r + S\,L_a')$.

With alternators the phase displacement of the E.M.F.'s is not fixed, but depends upon the load characteristics of the two engines; a method of calculating this displacement is given later. For alternators in parallel the same formulæ can be used as those which have already been deduced, provided that we take for Z_1 and Z_2 (the internal impedances) the equivalent values as obtained above.

The deductions already made for the general case of alternating E.M.F.'s in parallel therefore hold good for alternators, within the normal working limits. The case of equally excited machines and also that of similar machines are of particular interest and are therefore dealt with below.

Division of the Load between Two Machines equally excited in Phase. $E_1 = E_2$.

Synchronizing current $I_s = 0$.

$$I_1 = \frac{E_1 Z_2}{Z_1 Z_2 + Z(Z_1 + Z_2)},$$
$$I_2 = \frac{E_2 Z_1}{Z_1 Z_2 + Z(Z_1 + Z_2)}.$$

The currents in the two machines thus have the ratio—

$$\frac{I_1}{I_2} = \frac{Z_2}{Z_1},$$

i.e. the symbolic values of the currents are in the inverse ratio of the symbolic values of the equivalent impedances of the two machines.

$$\text{The main current } I = \frac{E_1(Z_1 + Z_2)}{Z_1 Z_2 + Z(Z_1 + Z_2)},$$
$$= \frac{E_1}{Z_1 Z_2/(Z_1 + Z_2) + Z}.$$

The equivalent internal impedance of the two machines is thus the parallel impedance of Z_1 and Z_2, or the total internal admittance is the sum of the machine admittances.

Division of the Load between Similar Machines.

$$Z_1 = Z_2.$$

1. *Equally excited, and in phase.*

$$\frac{I_1}{I_2} = \frac{Z_2}{Z_1} = 1,$$
$$I_1 = I_2 = E_1/(Z_1 + 2\,Z),$$
$$I = \frac{E_1}{Z_1/2 + Z}.$$

Main potential difference V

$$= E_1 - I_1 Z_1 = E_1 - (E_1 Z_1)/(Z_1 + 2\,Z),$$
$$= E_1 \left(\frac{2\,Z}{Z_1 + 2\,Z}\right).$$

2. *Equally excited and mechanical phase displacement of a electrical radians.* $E_2 = E_1(\cos a - j \sin a)$.

In the practical working of alternators a is always a small angle, so that we may take—

$$\cos a = 1, \text{ and } \sin a = a,$$

whence $\qquad E_2 = E_1 - j\,a\,E_1.$

$$\text{Synchronizing current } I_s = \frac{(E_1 - E_2)Z}{Z_1 Z_2 + Z(Z_1 + Z_2)},$$
$$= \frac{j\,a\,E_1 Z}{Z_1(Z_1 + 2\,Z)}.$$

* A. E. Clayton. A method for determining the total equivalent reactance of an alternator winding, and the calculation of the voltage regulation. *Electrician*, vol. 73, p. 90, 1914.

$$\text{Current } I_1 = \frac{E_1}{Z_1 + 2Z} + \frac{j\,a\,E_1 Z}{Z_1(Z_1 + 2Z)},$$
$$= \frac{E_1}{Z_1 + 2Z}\left(1 + j\,a\frac{Z}{Z_1}\right).$$

$$\text{Current } I_2 = \frac{E_2}{Z_1 + 2Z} - \frac{j\,a\,E_1 Z}{Z_1(Z_1 + 2Z)},$$
$$= \frac{E_1 - j\,a\,E_1}{Z_1 + 2Z} - \frac{j\,a\,E_1 Z}{Z_1(Z_1 + 2Z)},$$
$$= \frac{E_1}{Z_1 + 2Z}\left[1 - j\,a\left(1 + \frac{Z}{Z_1}\right)\right].$$

$$\text{Main current } I = \frac{E_1}{Z_1 + 2Z}(2 - ja).$$

The calculation of the distribution of the load between two similar machines is thus reduced to very simple equations.

So far we have calculated the distribution of the currents for a given load impedance. It is frequently desirable to calculate the manner in which a given load current is shared by the two machines.

We have
$$E_1 = I_1 Z_1 + I Z,$$
$$E_2 = I_2 Z_2 + I Z,$$
and
$$I_1 + I_2 = I.$$

Whence
$$E_1 - E_2 = I_1 Z_1 - (I - I_1) Z_2;$$
$$I_1 = I\frac{Z_2}{Z_1 + Z_2} + \frac{E_1 - E_2}{Z_1 + Z_2};$$
and
$$I_2 = I\frac{Z_1}{Z_1 + Z_2} - \frac{E_1 - E_2}{Z_1 + Z_2}.$$

Expressed in this form it is extremely simple to calculate the characteristic curves. The term $(E_1 - E_2)/(Z_1 + Z_2)$ is the value of the synchronizing current at no load.

Table VIII below gives the results of such calculations.

$E_1=500$. $E_2=500-50j$. $Z_1=0{\cdot}018+0{\cdot}72j$. $Z_2=0{\cdot}012+0{\cdot}48j$.

$$\frac{Z_1}{Z_1 + Z_2} = \frac{3}{5};\ \frac{E_1 - E_2}{Z_1 + Z_2} = \frac{50j}{0{\cdot}03 + 1{\cdot}2j} = 41{\cdot}5 - 1j.$$

TABLE VIII.

I	I_1	I_2
0	$41{\cdot}5 + 1j$	$-41{\cdot}5 - 1j$
50	$61{\cdot}5 + 1j$	$-11{\cdot}5 - 1j$
100	$81{\cdot}5 + 1j$	$18{\cdot}5 - 1j$
150	$101{\cdot}5 + 1j$	$48{\cdot}5 - 1j$
200	$121{\cdot}5 + 1j$	$78{\cdot}5 - 1j$
250	$141{\cdot}5 + 1j$	$108{\cdot}5 - 1j$
300	$161{\cdot}5 + 1j$	$138{\cdot}5 - 1j$
350	$181{\cdot}5 + 1j$	$168{\cdot}5 - 1j$
400	$201{\cdot}5 + 1j$	$198{\cdot}5 - 1j$

The calculations for other values of I out of phase with E_1 are quite similar.

DETERMINATION OF THE PHASE DISPLACEMENT BETWEEN TWO ALTERNATORS WORKING IN PARALLEL.

In actual practice alternators do not work with a fixed mechanical phase displacement. With two machines working in parallel the manner in which they share the load (watt component) depends entirely upon the engine characteristics. The mechanical displacement between the machines adjusts itself automatically so that each engine has to deal with its proper load. The wattless component of the main current is shared by the machines according to their relative excitations, the machine with the larger excitation contributing the greater part of the wattless current. It is necessary then to be able to calculate the phase displacement between the machines. From the engine speed-output characteristics the manner in which the two machines divide the load can be determined with fair accuracy (see Fig. 6). Hence we know also to a close approximation the ratio W_1/W_2 of the watt outputs of the alternators.

We have already obtained expressions for the values of the various currents; from these expressions we can obtain

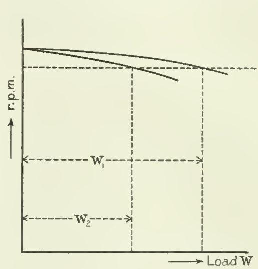


FIG. 6.

the values of the power developed by the two machines, from which we find for machines similarly excited—

Phase displacement a

$$= \frac{R(W_1 X_1 - W_2 X_2)}{(W_1 + W_2)[R^2 + X^2 + X(X_1 X_2)/(X_1 + X_2)]}.$$

The proof of this formula is given in the Appendix.

The author proposes to check the formula by referring back to Table IV, where several cases have been calculated for two machines having a phase displacement of one-tenth of an electrical radian.

$$X_1 = X_2 = 0{\cdot}8$$

CASE 1.—*Unity power factor.* $Z = 2{\cdot}5$; $R = 2{\cdot}5$; $W_1 = 63{,}750$; $W_2 = 33{,}600$.

$$a = \frac{2{\cdot}5 \times 0{\cdot}8\,(30{,}150)}{97{,}350 \times 6{\cdot}25} = 0{\cdot}099.$$

CASE 2.—*Power factor* 0·4 *lagging.* $R = 1$; $X = 2{\cdot}29$; $W_1 = 28{,}650$; $W_2 = 15{,}700$.

$$a = \frac{0{\cdot}8 \times 27{,}100}{30{,}200\,(6{\cdot}25 - 2{\cdot}29 \times 0{\cdot}4)} = 0{\cdot}100.$$

CASE 3.—*Power factor* 0·6 *leading.* $R = 1{\cdot}5$; $X = -2$; $W_1 = 56{,}750$; $W_2 = 21{,}500$.

$$a = \frac{1{\cdot}5 \times 0{\cdot}8 \times 35{,}250}{78{,}250\,(6{\cdot}25 + 0{\cdot}8)} = 0{\cdot}099.$$

Thus the angle of phase displacement between two alternators can readily be calculated provided that the engine characteristics and the equivalent reactances of the two windings are given.

Three Alternators in Parallel.

We have—

$$E_1 = I_1 Z_1 + (I_1 + I_2 + I_3) Z,$$
$$E_2 = I_2 Z_2 + (I_1 + I_2 + I_3) Z,$$
$$E_3 = I_3 Z_3 + (I_1 + I_2 + I_3) Z.$$

Solving these equations we obtain—

$$I_1 = \frac{E_1 Z_2 Z_3 + Z\{(E_1 - E_2) Z_3 + (E_1 - E_3) Z_2\}}{Z Z_1 Z_2 Z_3 (1/Z + 1/Z_1 + 1/Z_2 + 1/Z_3)};$$

and similar expressions for I_2 and I_3.

The load component of the current I_1

$$= \frac{E_1}{Z Z_1 (1/Z + 1/Z_1 + 1/Z_2 + 1/Z_3)},$$
$$= \frac{E_1}{Z_1 + Z (Y_1 + Y_2 + Y_3)/Y_1}.$$

The synchronizing component of the current I_1 is obtained from—

$$I_{s1} = \frac{E_1 - E_2}{Z_1 Z_2 (1/Z + 1/Z_1 + 1/Z_2 + 1/Z_3)} + \frac{E_1 - E_3}{Z_3 Z_1 (1/Z + 1/Z_1 + 1/Z_2 + 1/Z_3)}$$
$$= \frac{E_1 - E_2}{(Z_1 + Z_2) + Z_1 Z_2 (1/Z + 1/Z_3)} + \frac{E_1 - E_3}{(Z_3 + Z_1) + Z_3 Z_1 (1/Z + 1/Z_2)},$$

and similar expressions for I_{s2} and I_{s3}.

The total current $I = \frac{1}{Z} \Sigma \frac{E_1}{Z_1 (1/Z + 1/Z_1 + 1/Z_2 + 1/Z_3)},$

$$= \frac{1}{Z (1/Z + 1/Z_1 + 1/Z_2 + 1/Z_3)} \Sigma \frac{E_1}{Z_1}.$$

The problem is thus completely solved as in the case of two machines in parallel, and similar deductions can be obtained from the equations.

Determination of the Phase Difference between the Induced E.M.F. and the Terminal Voltage.

Actually the value of the real induced E.M.F. will not be that obtained from the vector diagram, since the armature reaction reduces its value. The value used in the vector diagram is the total E.M.F. induced on open circuit with the same excitation as on full load.

In the vector diagram, Fig. 7, ωL_r is the true reactance of the winding, ωL_a is that equivalent to the armature reaction. O E is the true induced E.M.F., O E′ is the fictitious value and is equal to the open-circuit E.M.F. The total lag of the terminal pressure behind the machine vector is equal to the angle E O V, of which E′ O E is due to the distorting effects of the armature reaction, and E O V is due to the true reactance of the winding.

Let θ = angle E′ O E, and take the reference vector in phase with the terminal pressure. Then the expression for the E.M.F. is given by—

$$O E' = E_1 (\cos\theta + j \sin\theta),$$
$$= E_1 \cos\theta + E_1 j \sin\theta.$$

Hence $\quad E_1 \cos\theta + E_1 j \sin\theta = V + I_1 Z_1.$

The output of the machine = real part of $I_1 V$, *i.e.* of

$$\left(\frac{E_1 \cos\theta + E_1 j \sin\theta - V}{Z_1}\right) V.$$

$$W_1 = \frac{E_1 V X_1 \sin\theta + R_1 (E_1 V \cos\theta - V^2)}{R_1^2 + X_1^2}.$$

$R_1^2 + X_1^2 = X_1^2$ for all practical purposes, hence—

$$W_1 = \frac{E_1 V \sin\theta}{X_1} + \frac{R_1 V}{X_1^2} (E_1 \cos\theta - V).$$

The second term is exceedingly small, R_1/X_1^2 being of the order of 1/250 and $E_1 \cos\theta$ being nearly equal to V. Hence to a close approximation—

$$\sin\theta_1 = \frac{W_1 X_1}{E_1 V}.$$

Similarly for another machine feeding into the same busbars—

$$\sin\theta_2 = \frac{W_2 X_2}{E_2 V}.$$

Hence $\quad \sin\theta_1 - \sin\theta_2 = \frac{W_1 X_1}{E_1 V} - \frac{W_2 X_2}{E_2 V},$

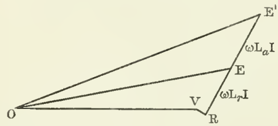


Fig. 7.

and for the small angles obtaining in practice—

$$\alpha = \theta_1 - \theta_2 = \frac{W_1 X_1}{E_1 V} - \frac{W_2 X_2}{E_2 V}.$$

For equally excited machines—

$$\alpha = \theta_1 - \theta_2 = \frac{W_1 X_1 - W_2 X_2}{E_1 V}.$$

The value α is the phase displacement between the two machines. Expressed in this form the formula is perhaps more suitable for calculations than the one given earlier, for all cases when the busbar potential difference is given. In the Appendix the two expressions are shown to be equivalent.

Many Alternators in Parallel.

When dealing with the parallel operation of more than two alternators the calculations are simplified by the fact that the potential difference between the busbars can now be taken as known.

Taking the reference vector in phase with V, we then have $E_1 \cos\theta + j E_1 \sin\theta = V + I_1 Z_1$; and for the values of θ obtaining in practice, neglecting the alternator resistance—

$$E_1 + j E_1 \theta = V + j I_1 X_1,$$

whence $\quad I_1 = E_1 \theta / X_1 - j (E_1 - V)/X_1,$

whence $\quad I_1 = W_1/V - j (E_1 - V)/X_1,$

since $\sin\theta = W_1 X_1 / E_1 V$.

Of this the watt component is the real term W_1/V, and the wattless component is $(E_1 - V)/X_1$.

Transformers in Parallel.

For convenience the author will first deal with the case in which the transformation ratio is unity. It is well known that such a transformer can be replaced by the equivalent circuit shown in Fig. 8.

Let I_{01} be the magnetizing current of the transformer,
Z_1' and Z_1'' be the primary and secondary leakage impedances,
and Z_{01} be the equivalent impedance on open circuit.

$$Z_1 = \text{the total leakage impedance} = Z_1' + Z_1''.$$

$$\begin{aligned} E &= (I_1 + I_{01}) Z_1' + I_1 Z_1'' + I Z, \\ &= I_{01} Z_1' + I_1 (Z_1' + Z_1'') + I Z, \\ &= I_{01} Z_1' + I_1 Z_1 + I Z. \end{aligned}$$

Whence
$$E - I_{01} Z_1' = I_1 Z_1 + I Z \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Similarly for the second transformer working in parallel with the first—

$$E - I_{02} Z_2' = I_2 Z_2 + I Z \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and
$$I = I_1 + I_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Solving these equations, we get—

$$I_1 = \frac{(E - I_{01} Z_1') Z_2}{Z_1 Z_2 + Z(Z_1 + Z_2)} + \frac{(I_{02} Z_2' - I_{01} Z_1') Z}{Z_1 Z_2 + Z(Z_1 + Z_2)};$$

$$I_2 = \frac{(E - I_{02} Z_2') Z_1}{Z_1 Z_2 + Z(Z_1 + Z_2)} - \frac{(I_{02} Z_2' - I_{01} Z_1') Z}{Z_1 Z_2 + Z(Z_1 + Z_2)};$$

$$I = \frac{(E - I_{01} Z_1') Z_2 + (E - I_{02} Z_2') Z_1}{Z_1 Z_2 + Z(Z_1 + Z_2)}.$$

In general the second terms in the expressions for I_1 and I_2 can be omitted, and we have—

$$I_1 = \frac{(E - I_{01} Z_1') Z_2}{Z_1 Z_2 + Z(Z_1 + Z_2)}; \quad I_2 = \frac{(E - I_{02} Z_2')}{Z_1 Z_2 + Z(Z_1 + Z_2)} \quad (4)$$

For the secondary potential difference we have—

$$V = E - I_{01} Z_1' - I_1 Z_1.$$

In the majority of cases the effect of the magnetizing current can be neglected—

$$I_1 = \frac{E Z_2}{Z_1 Z_2 + Z(Z_1 + Z_2)}; \quad I_2 = \frac{E Z_1}{Z_1 Z_2 + Z(Z_1 + Z_2)};$$

and
$$I = \frac{E(Z_1 + Z_2)}{Z_1 Z_2 + Z(Z_1 + Z_2)};$$

i.e. the same expressions as for equally excited alternators in phase. These expressions are sufficiently accurate for

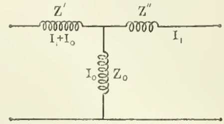


Fig. 8.

ordinary purposes. For more exact purposes the expressions (4) may be used.

The terms I_1, I_2, and I, give the values of the secondary currents. To obtain the primary currents we have—

$$\text{Primary current } (1) = I_{01} + I_1,$$
$$\text{Primary current } (2) = I_{02} + I_2.$$

Experimental Results.

To check the above, experiments have been carried out on two Berry transformers, the primaries of which consisted of two windings in parallel. By using these two windings as primary and secondary respectively, a 1 : 1 transformer was obtained. The two transformers being similar, a reactance coil was introduced in the secondary

Table IX.—*Transformers in Parallel—Experimental Results.*

	Test	K	L	M	N	P
Observed Readings	Pressure, E volts	90	90·5	90·5	90	91
	Primary Current, I_1' amps.	9·0	6·8	7·6	6·8	6·6
	„ „ I_2' „	13·2	10·5	13·5	15·1	15·5
	Total Primary Current, $I_{,,}'$ amps.	21·2	15	18·2	18·2	18·2
	„ Secondary „ I „	13·7	11·5	15	15	15
	Volts, V	86	84	82	82	82
	Power, W	720	990	1,230	1,230	1,230
Calculated Symbolic Values	[Z]	$3·8 + 5j$	7·3	5·5	5·5	5·5
	[Z_1]	$0·5 + ·96j$	$0·5 + 1·7j$	$0·5 + 1·7j$	$0·5 + 3·5j$	$0·5 + 4·4j$
	[Z_2]	0·4	0·4	0·4	0·4	0·4
	[I_1]	$-0·8 - 4·4j$	$1·1 - 2·2j$	$1·4 - 2·9j$	$0·4 - 1·7j$	$0·3 - 1·3j$
	[I_2]	$9·5 - 6·2j$	$10·6 + 2·1j$	$14 - 2·7j$	$15·2 + 1·6j$	$15·3 + 1·3j$
	[I]	$8·7 - 10·6j$	11·7	15·4	15·6	15·6
	[I_1']	$-0·8 - 9·4j$	$1·1 - 7·2j$	$1·4 - 7·9j$	$0·4 - 6·7j$	$0·3 - 6·3j$
	[I_2']	$-9·5 - 10·2j$	$10·6 - 1·9j$	$14 - 1·3j$	$15·2 - 2·4j$	$15·3 - 2·7j$
	[$I_{,,}'$]	$8·7 - 19·6j$	$11·7 - 9·1j$	$15·4 + 9j$	$15·6 - 9·1j$	$15·6 - 9j$
Calculated R.M.S. Values	Primary Current, I_1	9·4	7·2	8·0	6·7	6·4
	„ „ I_2	13·4	10·6	14	15·3	15·4
	Total Primary Current, $I_{,,}$	21·4	14·8	18	18·1	18·1
	„ Secondary „ I	13·7	11·7	15·4	15·6	15·6

$I_{01} = 5$ amps. ; $I_{02} = 4$ amps.

circuit of one of them as shown in the diagram of connections (Fig. 3). The effect is obviously the same as increasing the secondary leakage. The actual leakage between the two windings was very small and the transformers being worked at one-half the normal frequency the reactance was so small as to be much less than the resistance. In order to obtain relatively large magnetizing currents the working pressure was about 60 per cent above the normal. The test figures are given in Table IX and it will be noted that the results are in agreement with the calculated theoretical values.

In the case where the secondary E.M.F.'s are not exactly equal, it is best to work in terms of the actual secondary E.M.F.'s on open circuit, and reduce the primary impedances in terms of the secondaries in the usual manner. The difference in E.M.F. will give rise to a circulating current equal to $\frac{(E_1-E_2)\,Z}{Z_1 Z_2 + Z\,(Z_1+Z)}$, which, for a transformer, where Z_1 and Z_2 are small compared with Z, is practically constant and equal to $\frac{E_1 - E_2}{Z_1 + Z_2}$. The equations for this case are the same as for two alternators in phase but with different excitations.

Résumé.

By the aid of the symbolic method due to Steinmetz problems connected with the parallel operation of sources of alternating currents can be solved as readily as similar problems connected with continuous currents.

In the method given by the author the equations deduced in their general terms would hold good for both continuous and alternating currents.

The whole method is based upon sine functions, although if necessary with non-sinusoidal E.M.F.'s each harmonic can be considered separately. In addition, in the case of alternators, it is based upon an equivalent reactance due to the combined effects of reaction and reactance. A method of obtaining a correct value for this equivalent reactance has been given by the author in the *Electrician*.*

APPENDIX.

To Determine the Mechanical Lag between Two Machines.

The manner in which the machines divide the total watt output is determined by the engine characteristics. The present calculations will therefore assume equally excited machines, and the alternator resistances will be neglected. We have—

$$I_1 = \frac{j\,E_1 X_2 + j\,a\,E_1 (R + j\,X)}{-X_1 X_2 + (R + j\,X)\,(j\,X_1 + j\,X_2)},\ \text{say} = A + j\,B.$$

To obtain the mean watts we multiply the above by the symbolic expression for the E.M.F., or say $(C + j\,D)$, and we have the mean watts $= A\,C - j^2\,B\,D = A\,C + B\,D$.

$$I_2 = \frac{j\,E_1 X_1 - j\,a\,E_1 X_1 - j\,a\,E_1 (R + j\,X)}{-X_1 X_2 + (R + j\,X)\,(j\,X_1 + j\,X_2)}.$$

Proceeding as indicated above we obtain for the ratio of the total power developed by the two machines—

$$\frac{W_1}{W_2} = \frac{R(X_1+X_2)\,(X_2+aR)+aX[X(X_1+X_2)+X_1X_2]}{R(X_1+X_2)\,(X_1-aR-aX_1)-aX[X(X_1+X_2)-X_1X_2]}\ \text{approx.}$$

$$= \frac{R\,X_2 + a\,R^2 + a\,X^2 + a\,X\,X_1\,X_2/(X_1+X_2)}{R\,X_1 + a\,R^2 - a\,X^2 - a\,X\,X_1\,X_2/(X_1+X_2)}\ \text{approx.}$$

whence—

$$a\,[R^2+X^2+XX_1X_2/(X_1+X_2)]\,(W_1+W_2) = R(W_1X_1 - W_2X_2),$$

and—

$$a = \frac{R\,(W_1 X_1 - W_2 X_2)}{(W_1 + W_2)\,[R^2 + X^2 + X\,X_1\,X_2/(X_1 + X_2)]}.$$

This may also be written—

$$a = \frac{W_1 X_1 - W_2 X_2}{(W_1 + W_2)\left(\frac{R^2 + X^2}{R} + \frac{X\,X'}{R}\right)},$$

where X' is the equivalent reactance of the two alternators in parallel, *i.e.* X' equals $X_1 X_2/(X_1 + X_2)$. Hence—

$$a = \frac{W_1 X_1 - W_2 X_2}{V^2 + (W_1 + W_2)\,(X\,X'/R)},$$

$$= \frac{W_1 X_1 - W_2 X_2}{V^2 + (I\,V \sin\phi)\,X'},$$

where ϕ = angle of lag of the main current.

$$\therefore\ a = \frac{W_1 X_1 - W_2 X_2}{V\,(V + I\,X' \sin\phi)}.$$

$(I \sin\phi)X'$ is approximately equal to $E - V$; hence—

$$a = \frac{W_1 X_1 - W_2 X_2}{V\,E},$$

as obtained previously.

For unity power factor $X = 0$, and—

$$a = \frac{W_1 X_1 - W_2 X_2}{(W_1 + W_2)\,R}.$$

* *Electrician*, vol. 73, p. 90, 1914.

STATIC TRANSFORMERS FOR THE SIMULTANEOUS CHANGING OF FREQUENCY AND PRESSURE OF ALTERNATING CURRENTS.

By A. M. TAYLOR, Member.

(*Paper first received 23rd September*, 1913, *and in final form 5th May*, 1914; *read before the* BIRMINGHAM LOCAL SECTION *29th April*, 1914.)

SYNOPSIS.

Historical—the frequency changers of Joly, Vallauri, Spinelli, and Taylor.
Principle of Taylor's frequency changer.
Regulation.
Efficiency.
Uses of the apparatus.
Wireless telegraphy—ratios of 9 : 1 and 27 : 1 in one operation.
Appendix—explanation of the operation of the apparatus.

The object of the present paper is primarily to describe the method of employing static transformers for changing the frequency of alternating currents for power and lighting. In the latter part of the paper allusion will be made to the use of similar apparatus in connection with wireless telegraphy. In this direction, however, the author is not so familiar with what has been done as he is in the applications relating to power. It is therefore hoped that any incompleteness in the way of references to the work of other experimenters in the wireless field will be overlooked, in view of what is hoped will prove interesting matter relating to the frequency changer that the author has devised.

HISTORICAL.

The earliest public announcement of the invention of a frequency changer, as far as the author is aware, was made by the late M. Maurice Joly, and was communicated to the Académie des Sciences early in 1911. Two other inventors have also entered the field, both of them Italians, namely, Signor Vallauri, who, the author understands, has invented a frequency changer for doubling the frequency, and Signor Spinelli, who has invented an arrangement for trebling the frequency.

M. Joly's invention covered both forms of apparatus, namely, apparatus for taking a single phase of the supply and producing from it another single-phase supply either at double or treble the frequency. The first result was obtained by employing a continuous current to excite the static frequency changer. A very similar arrangement was independently worked out by the author. Whatever may be its advantages for wireless telegraphy, the fact of continuous current having to be used for excitation is rather a drawback as regards its application for power or lighting, and therefore the theory of this apparatus will not be discussed in this paper in detail as regards doubling the frequency. Those interested may find some valuable information in *La Lumière Électrique* * in a description of M. Maurice Joly's invention.

As regards trebling the frequency (the second form of apparatus), the principle of M. Joly's invention was essentially as follows:—He started with the idea that a sine wave can be split up, as shown in Fig. 1, into two waves—one of which is in the nature of a flat-topped wave with a steep front and end, and the other a somewhat peaky wave, the front and end of which have a very easy gradient. The difference between these two waves, or $\phi_1 - \phi_2$, gives a triple-frequency wave, as shown in the diagram. M. Joly suggested that by taking two transformers (A C and B D), of which the primary coils were A and B respectively, and the secondary coils C and D, and by applying a sine-wave electromotive force across the two primary coils A and B in series, waves of flux of the desired form would be obtained if one of the transformer cores (A) were saturated and the other (B) unsaturated. Further, he said that, considering the electromotive forces

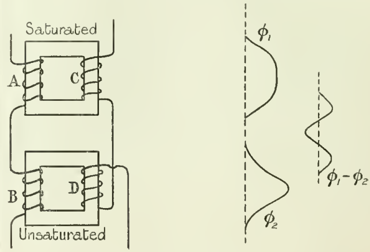


FIG. 1.—Joly's Arrangement.

from the secondary windings (which correspond with the differentiation of these waves of flux), by reversing one secondary winding so that its E.M.F. wave was opposed to that of the other secondary winding, a resultant effect would be obtained in the secondary circuit due to the difference of the two waves. In other words, one would get a triple-frequency electromotive force in the secondary circuit.

It will be seen at once from an investigation of the author's arrangement given later that this relation between the fluxes in the two cores is quite natural under particular conditions and exists in an aggravated form in his arrangement. The essential difference between M. Joly's arrangement and that devised by the author is that whereas in M. Joly's arrangement the secondary coils are wound both on the saturated and on the unsaturated cores and connected in series, this is not the case in the author's

* *Lumière Électrique*, vol. 14, p. 195, 1911.

arrangement, only one secondary coil being used, which is placed on the unsaturated core.

The difference in the operation of the two arrangements is also apparent, since in M. Joly's arrangement, owing to the fundamental condition of employing two secondary coils in series, it is necessary that the two half-waves should be distorted to exactly the right amount, and therefore the apparatus only works at its best efficiency under the conditions of a particular flux density in the saturated transformer and a particular value of the demagnetizing action in the unsaturated transformer; whereas in the author's arrangement the two flux densities can be varied quite independently and the induction can be raised to any desired degree in either, or the load varied to any desired amount in the working transformer. The magnetizing current itself can also be carried to very high limits and a large output thereby obtained from a given transformer. The author's arrangement, however, as will be seen from the description given later, generates an incomplete wave of electromotive force in any one phase, but the electromotive forces received from the three phases of the supply are so combined as to give a properly balanced single-phase wave of supply at the triple frequency.

To sum up, therefore, the essential difference between M. Joly's arrangement and that of the author is that whereas M. Joly takes a single phase of the supply and resolves a half-wave into three half-waves of electromotive force of triple the frequency, the author, on the other hand, takes a three-phase supply and from each individual phase of that supply, and from each half-wave of each phase, abstracts two incompletely formed half-waves of triple the frequency, supplementing these by other half-waves from the other two phases and delivering to the triple-frequency circuit a single-phase triple-frequency current. The author's arrangement, in fact, only works when transforming from three phases to a single phase. This statement does not apply, however, to his arrangement for obtaining a step-up of the frequency in the ratio of one to two.

As regards Signor Vallauri's invention, the author believes this to be substantially the same as that of M. Joly—but with some interesting developments—in that it transforms one phase of the supply into single-phase current at double the frequency. This method has been described in a paper read before the Associazione Elettrotecnica Italiana.*

The invention of Signor Spinelli differs from those of Vallauri and Joly in that it takes a three-phase supply and combines the three phases in such a way as to obtain a single-phase supply of triple frequency from the secondary coil. This frequency changer has been described by Signor Spinelli in a paper read before the Italian Society.†

In that paper Signor Spinelli pointed out that the arrangement should be particularly well adapted for use on three-phase railways (of which there are many in Italy) for the purpose of lighting railway stations, the frequency of the supply to the railway motors being only of the order of 15 periods per second, which periodicity is of course quite unsuitable for giving satisfactory lighting with incandescent lamps: whereas the frequency obtained (viz. 48 cycles per second) by increasing the fundamental frequency three-fold is eminently suitable for incandescent lighting.

* *Atti della Associazione Elettrotecnica Italiana*, vol. 15, p. 391, 1911; and *Electrician*, vol. 70. p. 582, 1912.

† *Elettricista*, vol. 1 (Ser. 3), p. 215, 1912; and *Electrician*, vol. 70, p. 97, 1912.

Signor Spinelli's arrangement is shown in principle in Fig. 2, and consists in taking three single-phase transformers and coupling their primary windings in star and their secondary windings all in series, and impressing on the primary windings an electromotive force from a three-phase supply of such a value that the primary cores are highly saturated. The author believes that the operation of this transformer may correctly be said to depend upon the fact that at a particular instant the current in one of the three limbs is double that in either of the other two, and consequently that the first-mentioned limb may be magnetically saturated at the moment that the other two are not so saturated; thus the electromotive forces generated in the three limbs no longer follow a true sine wave, as they do when the cores are entirely unsaturated. It will at once be granted that if they did follow a true sine wave, and the secondary windings were connected in delta, the resultant electromotive force in the

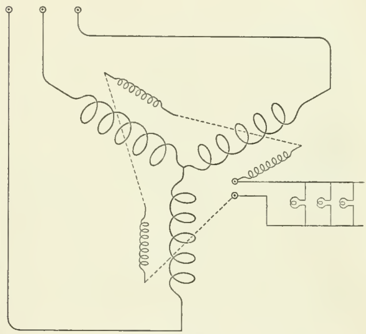


Fig. 2.—Spinelli's Arrangement.

secondary circuit would be zero. Hence it follows that the only electromotive force generated in the secondary circuit is that due to departure from a sine wave; in other words, the two coils that are in parallel at any moment act in a precisely similar way to the unsaturated transformer coils which the author employs in series with his saturated choking coil, the saturated choking coil in Signor Spinelli's apparatus being the coil which is in series at any moment with the other two.

The author understands that Signor Spinelli has obtained an efficiency of 60 per cent, so that evidently the method possesses possibilities, though this is hardly a sufficiently high efficiency to admit of its entering into serious competition with motor-generators in sub-stations for general lighting supply.

Taylor's Frequency Changer (Historical).

Before M. Joly, in France, had evolved his frequency changer, the author of the present paper had, without at first appreciating it, arrived at an arrangement giving a

three-fold change of frequency and converting from three-phase to single-phase supply in one operation.

The germ of this idea was evolved in the summer of 1909. The author was at that time considering a means of deforming the E.M.F. wave of an alternating-current supply, by flattening it at the commencement and end of the half-wave (with a view to facilitating the commutation in changing from alternating current to continuous current with a rotating rectifier). He proposed to draw current from the alternating-current mains, pass this current through a transformer wound on a saturated core, thus tending to give the wave of current a very sharp peak in a way that is well known (see Fig. 3, Curve C), and then to pass this deformed wave of current through an unsaturated choking coil in which the flux responded to the deformed wave of current so received, and in which in consequence two impulses of back electromotive force

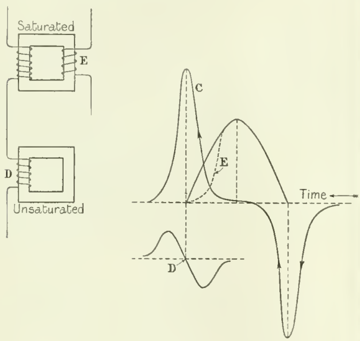


Fig. 3.

(see Fig. 3, Curve D) were generated, one at the commencement and end of each half-cycle of the fundamental electromotive force, thereby absorbing part of the electromotive force received from the mains at this instant and leaving a deformed E.M.F. wave generated in the saturated-core transformer, as shown in Fig. 3 (curve E).

It occurred to the author that it would be practicable, by winding a secondary coil on the unsaturated-core choking coil (D), to generate an E.M.F. wave of partially-complete triple frequency; and shortly after this he thought of employing a three-phase current and making up the missing parts of the E.M.F. wave from the other two phases. This led at once to the present invention.

Principle of Taylor's Frequency Changer.

The principle of the present invention will be clearly understood by reference to the accompanying figures. In Fig. 4 the connections are shown that would obtain if the arrangement were single-phase; this arrangement, however, is not practicable, owing to the triple-frequency impulses received being incomplete, and their having one half-wave missing in every series corresponding to a half-cycle of fundamental frequency.

It will be easiest to consider first what would happen in the choking coil if the primary winding of the working

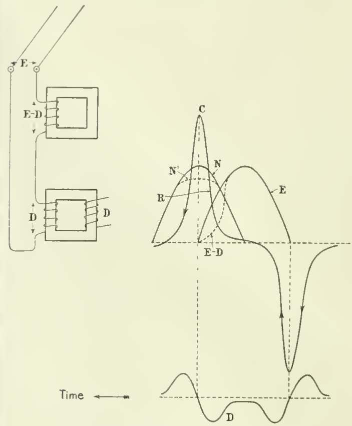


Fig. 4.—Principle of Taylor's Arrangement.

transformer were short-circuited; *i.e.*, in fact, the condition that would obtain if the saturated choking coil were connected direct to the supply mains.

The wave-form of the current which would then flow is

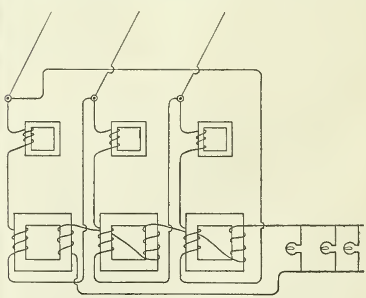


Fig. 5.—Connections of Taylor's Frequency Changer.

shown by Curve C in Fig. 4. It will be seen at once that if the current took this form the portion of the curve marked R would be that on which the rate of change of current was very rapid; and in consequence if the

current undergoing this change could be passed through the primary coil of a transformer winding, on an unsaturated core, so that the flux virtually followed the current wave, the electromotive force in the secondary-coil windings on the core of this transformer would have the waveform marked D at the bottom of the figure. This, however,

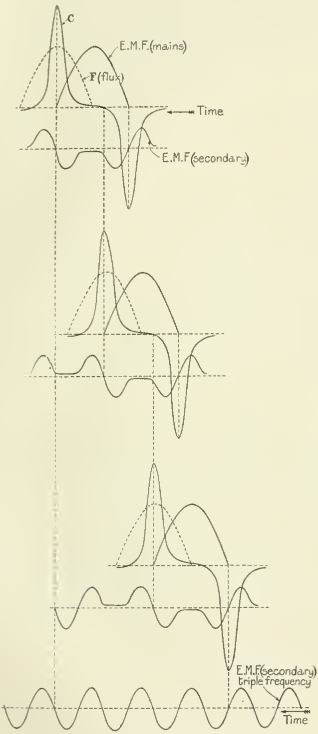


FIG. 6.—Principle of combining Three Phases to form a Single Phase (Taylor's Arrangement).

would leave a large period of the fundamental cycle in which no useful work was being done in the secondary coil of the transformer, and would be an unsatisfactory arrangement. Another disadvantage would be that the half-waves of electromotive force would not be exactly symmetrical, because the ascending and descending sides of the peak of the current are not exactly symmetrical about the axis. If, however, the arrangement is repeated on the three phases as shown in Fig. 5, these two difficulties disappear, the blank spaces being filled in by the impulses received from the other phases, and the dissymmetry of the positive and negative half-waves of electromotive force being nullified by corresponding impulses from other phases, in the manner indicated by Fig. 6.

A further investigation of the wave-form obtained in the secondary circuit (Fig. 6) shows that at any instant only two out of the three transformers are active, and the question then arises whether it is expedient to couple the secondary coils in series or in parallel. The author decided, and he believes rightly, that it would be better to couple them in parallel than in series, because if in

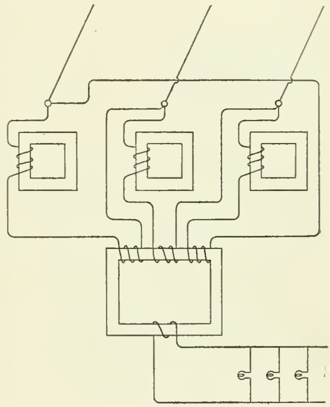


FIG. 7.—Present Form of Taylor's Arrangement.

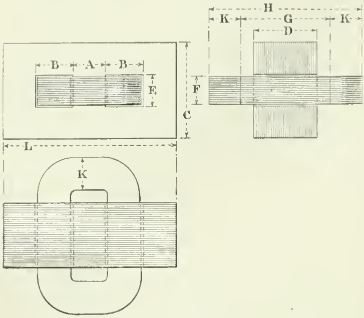
parallel the idle winding merely receives a small magnetizing current from the other two windings; whereas if they are in series the whole of the electromotive force of one winding is absorbed in driving the current through the impedance of the idle winding, leaving virtually only one winding effective. The author has confirmed this deduction experimentally.

In Fig. 6 the currents in the primary windings and the secondary electromotive forces in the three circuits are plotted in relation to one another on a time basis, and the way in which they combine in the secondary circuit can be easily seen.

An obvious deduction from what has already been stated is that it would be desirable to avoid difficulties with the idle current in the third phase by having a single-winding in the secondary, and by employing a common magnetized core, which is magnetized by the three primary currents having peaked wave-forms, as received from their respective choking coils. This is shown in Fig. 7.

Regulation.

It will be unnecessary to refer to the records of the early experiments, and the author will therefore come directly to the results obtained with the apparatus shown



TRANSFORMERS / CHOKING COILS

	Transformers 7kw.	Transformers 28kw.			Choking coils 7kw.	Choking coils 28kw.	
A	6·0	9·0		A	4·0	4·7	
B	3·0	6·25		B	3·0	6·7	
C	9·75	15·5		C	11·75	14·6	
D	3·5	9·35	net	D	3·5	9·9	net
E	3·75	6·5		E	3·75	5·45	
F	3·5	6·25		F	3·5	5·35	
G	5·0	12·0		G	5·0	14·75	
H	11·5	24·0		H	9·5	23·79	
K	2·75	6·0		K	2·75	4·52	
L	18·0	30·5		L	18·0	27·5	

All dimensions are in inches

Fig. 8.

in Fig. 7. The dimensions of the apparatus are given in Fig. 8, and the curve of regulation for the secondary load in Fig. 9. It will be noticed that the load can be carried up to 7 kw. without the drop of pressure exceeding 8 per cent (*i.e.* 4 per cent up or down). There are means of improving this; but the value given suited the requirements for the present, and further experiments in this direction were deferred.

Efficiency.

The author has analysed carefully the losses obtaining in the experimental 7-kw. set, both by wattmeter and by calculation from the measured currents, etc., and he has got out a design for a 28-kw. transformer which has an estimated efficiency of approximately 86–88 per cent. This set is now being constructed. On a 100-kw. size the author would certainly expect to get an efficiency of over 90 per cent, and on a 500-kw. transformer 95 per cent.

The dimensions for a 28-kw. set are shown in Fig. 8.

Uses of the Apparatus.

One use of the apparatus would be the conversion of three-phase current, on systems having a frequency of 25 periods per second, to single-phase triple-frequency currents having a frequency of 75 periods, for lighting work.

The apparatus lends itself in such a case to competition with rotary-converter sub-stations. Instead of supplying continuous-current lighting from the latter, it would be possible in any town where there is a large network of high-tension three-phase mains to install kiosks, or small static "exploitation" sub-stations, at various points along the route, with transformers to reduce the pressure and increase the frequency. The current delivered in the secondary circuit of the frequency changer is single-phase current, but this is actually advantageous for such work, in that it only requires the low-tension main to be run as a single-phase main, and the wiring of consumers' premises may also be single-phase wiring without any question of unbalancing the supply. The transformers being also entirely self-regulating (there being no automatic apparatus to look after), the frequency changers are eminently suitable for fixing in kiosks, where they will have to work without attention for perhaps a month or more at a time.

Another use for this apparatus would be for those power consumers who obtain current at 25 periods on specially cheap terms for lighting purposes and have their power supply in the form of an extra-high-tension supply. In this case it would only be necessary for them to take a supply of low-tension current from the secondaries of their power transformers, lead this through the frequency changer, and use it for the lighting of their buildings at 75 periods. In some trades where bright illumination is required and very fine work has to be done, the eyes get tried even where a frequency of 25 per second is used, and on the premises of such consumers the frequency changer would prove a most useful adjunct in ensuring a satisfactory supply for lighting purposes.

For electric welding purposes, and possibly also in con-

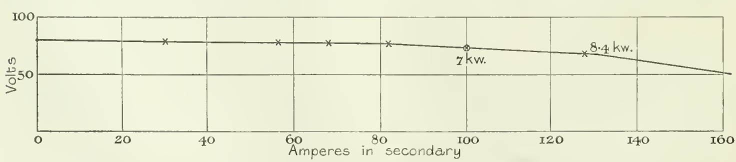


Fig. 9.—Regulation of Frequency Changer (Taylor's).

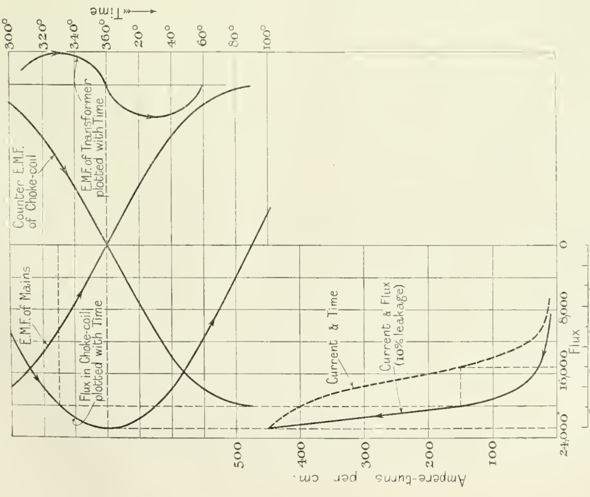


FIG. 10.—Three-fold Step-up.

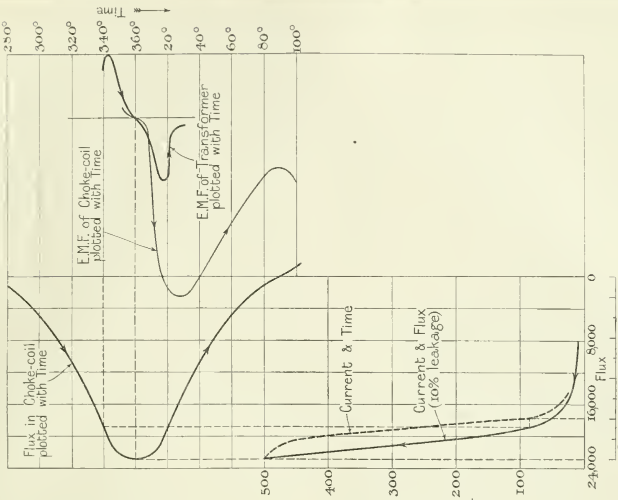


FIG. 11.—Nine-fold Step-up.

nection with single-phase electric furnaces, the frequency changer may find a useful field of application, its special feature being that any load (even a complete short-circuit) may be put upon the secondary winding without disturbing the "balance" of the power on a three-phase supply. In the case of certain three-phase furnaces the author is advised that the short-circuiting of the poles on any one phase may introduce extremely severe demands upon a single phase of the three-phase high-tension mains, upsetting the regulation and disturbing the supply to other consumers. It seems to him that here there should be a useful field for the frequency changer.

Another field in which the frequency changer may find a large sphere of usefulness is in connection with three-phase low-periodicity railway work, where it would be specially suitable for taking a supply from the mains at, say, 16 periods per second, and changing this to a supply for lighting at 48 periods per second for use in lighting the stations along the line.

The author anticipates that with a small modification the apparatus can be made reversible; for instance, 16·6 cycles might be obtained from 50 cycles. If so, this would open up the possibility of existing power concerns supplying current for electric furnaces or perhaps for railway work. The author has not yet had time, however, to experiment far in this direction; but he hopes to be able to give a demonstration of this on the occasion of the reading of this paper.

Wireless Telegraphy.

A brief consideration of Fig. 6 will lead to the conclusion that if we were to have nine phases of supply instead of three, and nine choking coils and working transformers (or nine choking coils and one "common" working transformer), the electromotive forces in the various secondary windings would combine in a similar way to give a current of nine times the primary frequency. The only condition that would be lacking would be that the durations of the secondary electromotive forces would be too long, and they would therefore overlap and partly nullify one another. This defect can be avoided by the simple expedient of generating an E.M.F. wave in the primary generator which is not a true sine wave.

Fig. 10 shows the natural period of time existing between the commencement of the rush of current through the choking coil and the crest of the current wave, where the choking coil is placed directly across the mains and a sine wave of electromotive force is applied. This can be employed for a three-fold step-up in the frequency.

Fig. 11 shows how by a very trifling alteration in the E.M.F. wave of the generator the above period has been shortened from about 50 electrical degrees to 20 degrees; this latter corresponding with a nine-fold step-up in the frequency. In a similar way the step-up in the frequency might be increased to 27-fold.

The author has not yet been able to make an experiment on the 27-fold step-up, but he has successfully made one on the nine-fold.

It will be understood that the apparatus tends to give the same multiple of the frequency whatever the original frequency may be. At the very high frequencies obtaining in wireless telegraphy, however, the eddy currents set up in the iron react upon the flux passing through the molecule and tend to demagnetize it.

E. F. Alexanderson of America has investigated this effect very carefully, carrying his experiments up to 200,000 cycles per second, and from the tabulated results the author finds that the extra ampere-turns required on the primary of a choking coil for a frequency changer stepping up to 100,000 periods per second are not at all prohibitive, provided that the iron is put in as thin as possible.

Using the 9 : 1 step-up arrangement the proposal would therefore be to build a generator having a wave-form approximately similar to the curve marked "E.M.F. of choke coil" in Fig. 11, and a periodicity of, say, 11,000 per second, which will give 99,000 periods on the high-tension winding of the frequency changer.

If it is found practicable to step up 27 times in one transformation, the generator need only be built for 3,666 periods in order to obtain 99,000 periods.

In conclusion, the author believes that he has been the first to show a practical application of the principle of employing as many phases of the supply as it is desired that the final frequency shall be a multiple of the original frequency, and combining all these independent waves of electromotive force into a common wave of electromotive force of the same number of times the original frequency that there are phases of supply.

APPENDIX.

A Simple Explanation of the Operation of the Apparatus.

A few further notes as to the operation of the apparatus may not be out of place.

Referring to Fig. 4, it will be noticed that the curve of flux (N′) is flat on the top, due to the back electromotive force (D) in the primary winding of the working transformer leaving the electromotive force (E–D) to be taken up by the choking coil instead of the electromotive force (E) of the mains. Now, when the electromotive force (E) is at its maximum, the rate of change of flux in the choking coil is also at its maximum, though the current in the choking coil is nearly zero. Again, when the electromotive force (E) is at its minimum, the rate of change of flux is also at its minimum, though the current in the choking coil (drawn from the mains) is at its maximum.

In other words, we may look upon the choking coil as a kind of valve which keeps out the electromotive force (E) of the mains from the primary coil of the working transformer at the time when the electromotive force of the mains is at its maximum, and lets it through on to the working transformer for about 60 electrical degrees on either side of the point of zero electromotive force in the mains.

We can also consider that by altering the shape of the electromotive force wave received from the mains the "valve" may be opened or closed for a longer or shorter period during each half-cycle of the supply, as is indicated by the relative time-values for the "current rush" in Figs. 10 and 11.

Power Factor.

The question of power factor has not been touched upon in this paper, for the reason that at the time of writing the paper the author was anticipating that he would be able very considerably to improve the power factor of his apparatus, and in fact to make it comparable with the power factor of other apparatus. Up to the present, however, he has been unable to experiment in this direction, and it therefore becomes important to consider how the low power factor, which is only of the order of 0·2, can be compensated for.

In the first place it is proposed to consider the question of improving the power factor by fitting phase advancers to the motors installed on consumers' premises. It must, however, be postulated that although this would be practicable in the case of those consumers whose plants are already installed, and who are therefore not likely to introduce phase advancers on any large scale under present conditions, yet things may be different in the near future, so that it would be necessary in that case to find other means of compensation. In a large system, however, of say 30,000 kw. size, there will no doubt be large motors aggregating perhaps 15,000 kw., or say 50 per cent of the aggregate power of the system, upon which it would pay to introduce phase advancers for the above purpose.

The author is advised that where the frequency is as low as 25 periods certain phase advancers which are already on the market could be applied at a cost of not much more than 5s. per kilowatt of the rating of the motors under consideration. The question then arises as to how far it would be practicable to introduce a lighting load on such a system, through the medium of frequency changers compensated for by phase advancers.

Referring to Fig. 12 it will be seen that if there is an existing motor load of 100 kw. at a power factor of 0·70 lagging, and if by means of phase advancers this is improved to 0·95 leading and a 40 kw. lighting load at 0·2 power factor is then superimposed on the system, the resultant power factor will be 0·77 ; this is a decided improvement, and the power consumer will gain considerably, his power factor being raised from 0·7 lagging to 0·95 leading. From this it will be seen that for every 100 kw. of motor load no less than 40 kw. of lighting load can be introduced by means of phase advancers on the existing motors of consumers. That is to say, on a 15,000 kw. motor load—the figure taken above—6,000 kw. of lighting load could be introduced by means of phase advancers; and the cost of the maintenance of these phase advancers, together with the interest and sinking fund on the same, works out at something like 0·06d. per unit, even if a load factor as low as 7 per cent is taken.

If, instead of a lighting load, we were considering, say, a furnace load and the use of phase advancers which step down the frequency, the additional cost on a probable load factor of something like 25 per cent would only be of the order of 0·02d. per unit, which would certainly not hamper in any way the selling price of the energy to such consumers. It should also be noted that this figure and the one previously given (0·06d.) include a fair margin for contingencies. It would thus appear to be profitable for the supply company themselves to install the phase advancers on consumers' premises without unduly hampering the consumer by the charge which would have to be made for this phase rectification.

Phase Rectification from Rotary Converter Sub-stations.

An alternative method of phase compensation, which, however, would only carry the compensation as far as the sub-station, would be the insertion of motor-generators in the sub-stations. These machines would be of sufficient rating to introduce a leading wattless component of current on the system. The author is alluding to rotary-converter sub-stations supplying a considerable continuous-current load, such as there are in most large

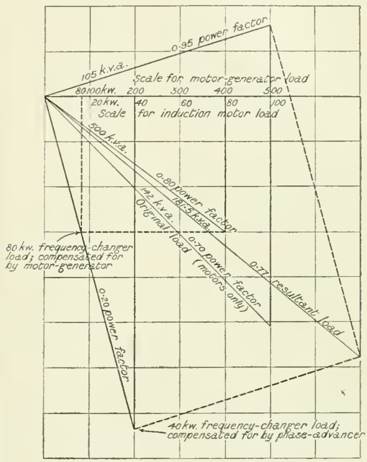


Fig. 12.

towns. It has been shown elsewhere* that if a 500 k.v.a. suitably-excited motor-generator is used to supply a continuous-current load of 375 kw., there could also be drawn from the E.H.T. mains by the alternating-current side of the machine a leading wattless current corresponding with that required by an induction-motor load of 500 k.v.a. having a power factor of 0·80. The vector curves given in Fig. 12 show that in this case the wattless component of the current would be the same as the wattless component for an 80-kw. load at a power factor of 0·2, corresponding with the power factor of the frequency changer on the primary side (the power factor on the secondary side is very nearly unity).

We thus arrive at the conclusion that we can take up an 80-kw. load on the frequency changer for every 375 kw. of load supplied on the continuous-current side of the motor-

* *Electrical Engineer*, vol. 39, p. 266, 1907.

generator, *i.e.* approximately 20 kw. for every 100 kw. of load on the continuous-current side of the sub-station. Now, the proportion of the copper and iron of the machine used for improving the power factor of the induction-motor load is that represented by 125 kw. (which would otherwise be available for an extra continuous-current load of that amount); and this at, say, £2 per kilowatt represents £250, which is the capital cost of obtaining an additional 80 kw. as a lighting load, or 250/80, *i.e.* £3·1 per kilowatt of lighting load taken up through the frequency changer.

It may here be remarked that the motors fed from the outgoing feeders on the E.H.T. side of the sub-station could be used to assist further in compensating for the power factor, thus providing for another 40 kw. of lighting load on every 100 kw. of induction-motor load so taken up.

Interest and sinking fund on the above £3·1 per kilowatt at 10 per cent represent approximately 6s. per annum per kilowatt, and at a 6·8 per cent load factor, representing approximately 600 hours' use per annum, this makes the cost per unit = 72/600d. = 0·12d. So that if, for instance, energy were sold for lighting purposes at 3d. per unit, the price would have to be raised by only $\frac{1}{8}$d. per unit on account of phase compensation, or by $\frac{1}{4}$d. per unit allowing a 100 per cent margin for other charges and for contingencies. If, however, electric furnaces were being supplied, having a load factor of perhaps 25 per cent, the last-mentioned figure ($\frac{1}{4}$d.) would be reduced to approximately 0·06d. per unit, which should not prove an undue handicap in the case of a charge of 1d. per unit.

To the above must of course be added the cost of the frequency changer itself, which is of the same order; but, even so, considering that this would bring in an entirely new class of load, the cost would not be at all prohibitive. The distribution costs would, as compared with continuous-current distribution from rotary-converter sub-stations, be saved the heavy expense of the latter and of the continuous-current cable networks from these sub-stations, which would much more than compensate for the cost of the frequency changers. The special field for the scheme would be on the outskirts of the areas fed by the rotary-converter sub-stations.

Discussion.

Mr. Chattock.

Mr. R. A. Chattock: I think the author is to be congratulated upon having arrived at results so much superior to those obtained by Joly and Spinelli. Fig. 6 shows a very even wave-form for the triple-frequency current, a very different result from that obtained by the other two experimenters. Of course this wave-form is, I believe, only a calculated one, but I gather that the author has satisfied himself experimentally that it is correct. The one drawback to the apparatus in its present form is the low power factor obtained in the circuit. I understand that it is something like 0·2. The author's suggestion to improve it by installing phase advancers on any large motors that might be connected to the same circuit is undoubtedly a step in the right direction. This method can, however, only apply in those neighbourhoods where there is a large power load in addition to the lighting load that it is proposed to supply at the higher frequency. In most industrial areas the power load is in a different district from the lighting load, and it is therefore doubtful whether it would be possible to correct the lighting load factor in this way to any great extent. The author referred to an actual case of an existing motor load of 100 kw. capacity at a power factor of 0·7 lagging, a lighting load of 40 kw. supplied at the triple frequency and at a power factor of 0·2 being superimposed on the systen. With phase advancers coupled to the motors so as to give a leading power factor of 0·95, the resultant power factor would be 0·77 lagging. I should like the author to explain what effect the superimposition of this lighting load on the power load would have on the resultant power factor if phase advancers are not employed. Then, again, if there are no motors or sub-stations in the neighbourhood supplied from the circuit, how would he propose to correct the power factor over a large system of distributing mains supplying current at triple frequency. Unless some correction is made, a large cost would have to be faced in laying down copper to accommodate the wattless component of the current.

Mr. Carter.

Mr. F. W. Carter: The author's ingenious arrangement is of great interest, but it seems to me that it would not make such good use of the material as is usual in ordinary electrical machinery for power purposes; probably this is in some way connected with the extremely low power factor. Altogether, I consider that the arrangement is more likely to be of use in connection with wireless telegraphy than in ordinary power work.

Mr. Engholm.

Mr. A. G. Engholm: I notice that the author claims a very good regulation for his apparatus, and if the latter can be supplied at a low price and the working costs are low there should be a very great field for its use, especially where low frequencies and low voltages are required, such as for electric furnaces, welding, etc. I think it would be interesting if the author could tell us what is the voltage drop in the choking coils used; also how much of the regulation is due to ohmic drop, and how much is due to the self-induction of the transformer.

Dr. Coales.

Dr. J. D. Coales (*communicated*): In his historical allusions I think that the author must have inadvertently omitted to mention that in investigating this subject he made use of a paper read by myself before this Local Section in 1908.* In that paper the effects of magnetic saturation in transformer cores were very fully discussed and illustrated by oscillograms; and on page 426 of the paper there is the following remark: "This curve marked 'D.C. Amps' shows how the direct current is thrown into ripples by the superposition upon it of an induced alternating current having twice the frequency of the applied voltage." Fig. 1 in the present paper, illustrating Joly's arrangement of 1911, is electrically similar to Fig. 3 of my paper of 1908. The author is to be congratulated on having made a great step in obviating the use of continuous currents in his frequency changer.

Professor Marchant.

Professor E. W. Marchant (*communicated*): The fre-

* J. D. Coales. A method of using transformers as choking coils and its application to the testing of alternators. *Journal I.E.E.*, vol. 42, p. 412, 1909.

essor hant.

quency changer described by the author should be of great use on low-frequency circuits in increasing the frequency for lighting. At the same time the flicker effect at 25 cycles with carbon-filament lamps has, I believe, been much exaggerated. With metal-filament lamps the variation in the light emitted is much greater, but in most cases I doubt whether the flickering is as noticeable as it is sometimes thought to be. With arc lamps the case is different and there is no doubt that the flicker is irritating. The most remarkable feature of the author's device is the high efficiency claimed for it. One would have expected that the high saturation necessary in the cores of the auxiliary choking coil would have entailed a much greater iron loss than that which actually occurs. Possibly this is due to the use of Stalloy for the choking coil and transformer cores. An efficiency of 86 per cent for a small frequency changer is much better than could be obtained with one of the rotating type. The extent to which frequency changers are used in the United States is often overlooked in this country. In connection with the Shawinigan transmission the plant for changing the frequency from 25 to 50 cycles for the lighting of Montreal would fill many of our medium-size central stations. The dimensions of the author's frequency changer for the same power appear to work out at a very much lower figure, and in addition there is the advantage of the diminished wear and tear with stationary plant. One of the most interesting suggestions that the author makes is that his plant might be used for producing high-frequency oscillations for wireless work. There is no physical objection to this. Experiments which I made many years ago, using frequencies up to 50,000 ∾, show that at such frequencies iron has, within the limits of experimental error, the same magnetic properties as it possesses at ordinary supply frequencies. There is some doubt as to whether at still higher frequencies iron possesses the same properties with strong magnetizing forces. The experiments of Alexanderson with small magnetizing forces appear to show, however, that its permeability at frequencies up to 200,000 ∾ is the same as it is at low frequencies, but that even with plates of 0·08 mm. thickness the skin effect is so great that the permeability never exceeds an effective value of 1,200. There seems no reason from the point of view of the molecular theory why iron should not behave in the same way with strong magnetizing forces as it does with weak ones. The efficiency of such an arrangement as that suggested by the author would naturally decrease with an increasing number of transformations, and there might be some difficulty in saturating the iron to such a degree as to give the necessary irregularity in the shape of the wave of magnetizing current. The further investigation of this device should prove very interesting, and it is to be hoped that it may result in the production of a new generator of high-frequency currents of practical value in wireless work.

Taylor. Mr. A. M. TAYLOR (*in reply*): Replying to Mr. Chattock, I would say that in my opinion it is not at all necessary that the power load should be in identically the same area as the lighting load. To emphasize this point I have prepared two diagrams (see Fig. A), the upper of which represents a power load farther out from the generating station than the lighting load, and the lower of which represents the reverse conditions. It is assumed that all lighting loads near the generating station are at present supplied by rotary-converter sub-stations. Considering Mr. Taylor. first the upper diagram, it will be noticed that the resultant power factor as far as the lighting load is 0·8, or more than 10 per cent higher than it would be in the case of a power load; while beyond the lighting area the power factor is 0·95, or over 30 per cent better. Hence there is a considerable saving in cable to be credited to the scheme. In the lower diagram the power factor as far as the motor load is 0·8, and from there to the lighting load it is 0·2. We may here credit the frequency changer with a saving of 10 per cent on three miles of cable and debit it with the loss on the one mile of cable; which means that a charge of £1 7s. per kilowatt per mile, over and above that of the power load, must be debited to the frequency changer. If, however, the lighting load is situated more than a mile beyond the power load, it might be advisable to step up the pressure, since the frequency changer would do the stepping down. The greater the distance from the generating station at which these power areas are situated, the greater is the saving in cable supplying them with which the new arrangement is to be credited.

The cost of phase compensation by means of phase advancers on induction motors is so very low compared with that of increasing the amount of copper in the cables,

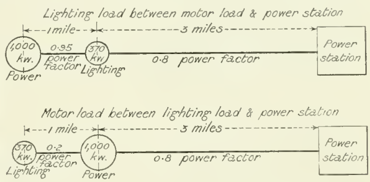


FIG. A.

that if there were a large motor load on one side of the town and a lighting load on the other side it would be possible in many cases considerably to over-compensate for power factor on the motor side; and the saving in cable thus effected would probably balance the extra expense on the lighting side, whilst the power factor of the generator would also be maintained high.

In the case where the supply authority installs its own frequency changers, it would be quite easy to arrange matters in this way, as the cost is thereby distributed over the whole system.

In making the above suggestions I do not wish it to be understood that I have by any means given up hope of improving the power factor of the frequency changer itself, and I only await opportunities of further experimenting in this direction.

Replying to Mr. Chattock's further question, a 10-kw. lighting load through a frequency changer may be superposed upon a 100-kw. motor load of 0·7 power factor, and the resultant power factor would be 0·62 without any compensation being employed. I would not recommend, however, more than 10 per cent being taken up in this way without compensation in some part of the system.

Replying to Mr. Carter, the scheme which I propose should cost considerably less in initial outlay and in main-

Mr. Taylor. tenance than a scheme involving rotary frequency changers, as accommodation would have to be provided for the latter, a special staff would be necessary to look after their running, and mains would have to be laid, such mains not being so suitable for taking up the power load. My scheme would also enable the existing high-tension power mains to be utilized for lighting purposes where they pass through a district on their way to some more distant district where there is a power demand.

I regret that I am not at the present moment in a position to give publicly the information asked for by Mr. Engholm.

Replying to Dr. J. D. Coales's remarks, I much regret that I did not refer to the valuable work described in his paper before the Birmingham Local Section in 1908. As far as I recollect, however, this work did not give me any clue to the design of the frequency changer, although I was much interested in it as a record of the wave-forms of the currents that flow in the case of saturated cores, upon which subject I was engaged at that time. The sentence quoted by Dr. Coales cannot, I think, have been noticed by me. It shows he appreciated that an induced E.M.F. of double frequency was generated under the conditions of his experiment; but it is, of course, a long way from this to the working out of an effective means of applying this property in a practical manner. For instance, Mr. R. C. Clinker of Rugby has reminded me of some investigations that he carried out in 1905, in which apparently he also pointed out how the triple-frequency currents were generated and could be obtained, but here again he went no further in the development of the apparatus than to make a suggestion. I regret very much that in this case also no reference was made in the paper to Mr. Clinker's early and valuable work.

I am much indebted to Professor Marchant for pointing out the saving in floor space and efficiency that should be obtained with static frequency changers as compared with rotating ones. Perhaps, however, I may be allowed to question whether the flicker due to 25 periods has been exaggerated. My only reason for making this statement is that it seems to me incredible, knowing the business ability of American engineers, that for these 10 years past they should have been installing hundreds of thousands of pounds' worth of plant every year for the express purpose of converting the lower periodicity into the higher, solely on account of a bogey. With regard to Professor Marchant's statement that the efficiency would naturally decrease with an increasing number of transformations, I may explain that I only employ one transformation whatever number of times the frequency is stepped up. As regards his further statement that "there might be some difficulty in saturating the iron to such a degree as to give the necessary irregularity in the shape of the wave of magnetizing current," I would explain that by the arrangement described in the paper (see Fig. 11) a high degree of saturation is rendered unnecessary, the rate of change of current being obtained with no greater exciting current than that with a three-fold step-up.

PROCEEDINGS OF THE INSTITUTION.

ANNUAL GENERAL MEETING OF THE 21ST MAY, 1914.

Proceedings of the 42nd Annual General Meeting of The Institution of Electrical Engineers, held on Thursday, 21st May, 1914—Mr. W. DUDDELL, F.R.S., President, in the chair.

The minutes of the Ordinary Meeting held on Thursday, 23rd April, 1914, were taken as read, and confirmed.

A vote of condolence with the family of the late Mr. Robert K. Gray, Past President, was passed by the meeting, the members standing in silence.

The President announced that no nominations having been received other than those made by the Council for the offices of President, Vice-Presidents, and Honorary Treasurer, the Council's nominees were, in accordance with Articles 50 and 51 of the Articles of Association, duly elected, and that the scrutineers (Messrs. F. B. O. Hawes, R. W. Hughman, and E. A. Nash) appointed at the meeting of the 23rd April, 1914, to examine the ballot papers for the election of new Ordinary Members of Council, had reported that the following persons had been duly elected as Ordinary Members of Council: Mr. J. Christie, Professor B. Hopkinson, F.R.S., Mr. G. W. Partridge, Mr. W. H. Patchell, Mr. R. J. Wallis-Jones, and Mr. W. B. Woodhouse. The Council for the year 1914–15 would therefore be constituted as follows:—

President.

J. F. C. SNELL.

The Past Presidents.

Vice-Presidents.

J. S. HIGHFIELD.
W. JUDD.
C. H. MERZ.
C. H. WORDINGHAM.

Honorary Treasurer.

R. HAMMOND.

Ordinary Members of Council.

A. B. ANDERSON.
F. E. BERRY.
R. A. CHATTOCK.
J. CHRISTIE.
E. RUSSELL CLARKE.
F. GILL.
CAPTAIN E. O. HENRICI, R.E.
PROFESSOR B. HOPKINSON, F.R.S.
A. W. MARTIN.
A. M. J. OGILVIE, C.B.
G. W. PARTRIDGE.
W. H. PATCHELL.
DR. A. RUSSELL.
W. RUTHERFORD.
A. H. SEABROOK.
ROGER T. SMITH.
R. J. WALLIS-JONES.
W. B. WOODHOUSE.

The Chairman and the immediate Past-Chairman of each Local Section.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

Mr. A. Home-Morton and Professor J. T. Morris were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Members.

Juttke, Julius, Ph.D.
Laidler, William Cranswick.
McBerty, Frank Robert.

Associate Members.

Ashworth, John.
Franks, Albert.
Gill, Robert Francis H.
Hore, Alfred Thomas S.
Levett, John Victor.
Taylor, Herbert Bardsley, Lieutenant-Commander, R.N.
Tipper, Ernest Edward.

Associates.

Day, William Richard B.
Mountain, William John.
Roemer, Charles William von.
Wilkins, Frederick Hayes.
Willcox, Francis Wallace.

Graduates.

Alexander, John Wallace.
Andrews, William Frederick.
Bailey, Charles Frederick.
Barsdorf, Leonard William.
Bostel, Alfred Charles.
Dainty, William Reginald.
Davies, Felix Carr.
Hull, Walter.
Ives, Edward Charles.
Jones, Reginald Gomer.
Lloyd, John Ambrose.
Lythgoe, Joseph.
Manly, Edward Harry.
Metcalf, Henry.
Rouse, Horace Frederick M.
Sawtell, Walter Stanley.
Shand, William Lamont.
Shaw, William John.
Sherwin, William Henry.
Tyler, Arthur Stewart.
Woodward, Charles Hemlet.

Students.

Crampton, Arthur Edward.
de Withnann, Henry Marie Sinclair.
Foote, Norman Victor.
Germann, Carl.
Howarth, Jr., A.
Kill, Ernest Frederick.
Lewis, Hubert John.
Linstow, Frederick Norman.
Ross-Bain, Grant.
Seagrave, Harry George.
Stone, Herbert John.
Tabor, Arthur Robert.
Tilson, Herbert Sydney.
Trutch, Charles Joseph Hyde.
Vowell, Christopher.

TRANSFERS.

Associate Member to Member.

Allom, Gilbert Fox.
Cordiner, Pratt.
MacMuldrow, William George P.
Thorne, Guy Stafford.

Associate to Associate Member.

Jennings, Edward Jennings.
Morgan, John David.

Graduate to Associate Member.

Nelson, Thomas John.
Stone, Arthur Albert.

Student to Associate Member.

Doig, Alexander McLaren.
Hutchison, Eric.
Woodward, Edward Hamilton E.

Student to Graduate.

Hornblower, Thomas Joseph.
Plowman, Ashley.
Rowell, John Periam.

Donations to the *Library* were announced as having been received from The Canadian Department of Mines (Mines Branch), Messrs. Constable & Co., J. Eck, N. H. Freeman, J. H. Havelock, A. Home-Morton, The Hydro-Electric Power Commission, Ontario, The Institution of Post Office Electrical Engineers, Marconi's Wireless Telegraph Company, C. H. Merz, T. E. Murray, Messrs. E. & F. N. Spon, and A. Stewart ; to the *Museum* from the family of the late Sir William H. Preece ; to the *Building Fund* from W. McGeoch, and W. M. Mordey ; and to the *Benevolent Fund* from The Associated Municipal Electrical Engineers of Greater London, H. C. Silver, J. H. Tonge, and W. B. Woodhouse, to whom the thanks of the meeting were duly accorded.

The PRESIDENT : I move "That the Annual Report as circulated * be received and adopted."

Mr. R. HAMMOND : I have pleasure in seconding that motion.

Mr. F. C. RAPHAEL : I should like to ask whether the Council can offer some explanation of the fact that instead of the membership having increased during the year there has been a decrease of 39. The diminution is small, but I find from last year's Report that the membership in the previous year increased by 547. I should also like to ask in regard to the efficacy of notices which are sent with the *Journal* instead of being distributed separately, as formerly. I think that a very good indicationof the effectiveness of the new arrangement would be obtained if we were told, as on a previous occasion, the number of votes given in the ballot for the election of Members of Council.

Mr. W. C. P. TAPPER : I notice that reference is made in the Report to the appointment of a Municipal Loans Committee. I should like to know whether we may have some information as to the composition of that Committee, and whether those who are primarily interested in municipal work can have some assurance that they will be adequately represented on the Committee. I should also like to know whether the Model General Conditions which have recently been issued have received the approval of, the British Electrical and Allied Manufacturers' Association and of the Incorporated Municipal Electrical Association.

Mr. R. HAMMOND : The decrease of 39 in the membership must be considered in conjunction with the fact that the present membership totals 508 more than it did two years ago. The very large increase of membership which took place the year before last was due to the Council's intimation that the increase in the subscriptions and the Associate Membership Examination would come into force the following year. The increase in the membership in that particular year was 547, and on deducting the decrease of 39 during the past year we obtain an increase of 508 to our former membership of 6,537, making our present total membership 7,045. It is with that figure of 6,537 that we have to make our comparisons. If the figures were taken over a series of years I feel certain that members would acknowledge that it is very gratifying for the Institution that its membership has increased so much. When, however, one particular year is compared with a year in which there was such an exceptional increase I think it will be admitted that it is only reasonable that there should be a slight decrease. When subscriptions were raised there were those who said that we should lose 20 per cent of our members ; when therefore it comes to a decrease of only 39 on a membership of 7,000, I think that those of us who believed that we should maintain our position were sound in that prophecy.

The PRESIDENT : I do not think that the fact that the ballot papers were enclosed with the *Journal* had any appreciable effect, because rather more ballot papers were returned this year than were returned last year, when they were sent out in separate envelopes. Nevertheless, the Council has decided to send out the ballot papers in the future in envelopes. I may also add that approximately 23 per cent of the ballot papers sent out were returned. The Municipal Loans Committee consists of two engineers connected with supply companies, three municipal engineers, and three other members. The Model General Conditions have not yet been formally adopted either by the British Electrical and Allied Manufacturers' Association or by the Incorporated Municipal Electrical Association, but I think that both those Associations are in full agreement with the majority of the clauses.

* See p. 632.

Mr. H. Hirst: I should like to make a short statement with regard to the Industrial Committee, the dissolution of which has been mentioned. Although, as a Member of Council, I agree with the wording of the Report, absence abroad prevented me from taking any part in the framing of it, and I am afraid that the Report may be misunderstood by some of the members who are interested in this question. I have no fault to find with the powers that were conferred on the Industrial Committee, so far as the Council could confer powers, but it does not seem to be generally known that the Council considered it essential that the Industrial Committee should not deal with matters which might be construed to have a political bearing. All the Members of Council who were members of the Committee were anxious to respect this wish, but when it is considered that in this country concessions have been granted by Parliament to some 400 municipalities in regard to electricity supply stations, it is very difficult to find subjects connected with municipal electricity supply that do not touch politics. This was also proved by the condition of affairs which arose at the time Dr. Klingenberg read his paper, when the Council had some fears that the paper might lead to a political discussion. The Council had other wishes which do not appear in the constitution of the Committee, but which have been respected by the Committee. The Council considered that questions which were to the detriment of a certain section of its members should not be dealt with, and some members of the Industrial Committee were anxious to respect that wish. Other members of the Committee felt that if a proposition that is for the benefit of the whole industry is brought forward, some section may have to give way or to suffer slightly. The Council having made this ruling, however, it was difficult for the Industrial Committee to choose suitable subjects which were likely to meet with the approval of the Council. Well-known and respected members of the Council thought that the high standard of the Institution might suffer if it lent its name to discussions dealing with money matters, such as finance or trade discounts, that were likely to enter into the discussion of industrial questions. Whilst within those limitations the Industrial Committee had full powers, I think it is due to myself as Chairman and to some of the members who differ from those views, to say that the above were some of the limitations of the constitution which are not referred to in the Report, and which acted against the possibility of the Industrial Committee doing such work as it was hoped could have been done. I do not say this as a complaint or as a reproach, but I think it should be understood by those who take an interest in the question.

The resolution was then put and carried unanimously.

The President: I shall now call upon the Honorary Treasurer to move the adoption of the Accounts and Balance Sheet for the year ended 31st December, 1913.

Mr. R. Hammond: As the Accounts have been published in the *Journal** there is no need for me to go into them in detail. I think that the figure which will more particularly be considered satisfactory is the one which appears at the end of the Revenue Account. The unexpended revenue for the year 1913 was £2,832 12s. 3d., compared with £1,237 19s. 5d. for the previous year. The total income of the year was £19,802, compared with £17,606 for the preceding year, and shows an increase of £2,196. On the other hand we have had to increase our staff, so that our total expenditure on Revenue Account and on the Local Sections amounted to £15,410; and as our expenditure on Capital Account amounted to £1,559, the total expenditure amounted to £16,969. The £15,410 expended last year on Revenue Account compares with £14,181 in the previous year, and the expenditure on Capital Account of £1,559 compares with £2,187, the total expenditure being £16,969 for 1913 and £16,368 for 1912, a difference of £601. Our assets this year show an increase of £4,000 compared with those at this time last year. I think there is no other item in the Accounts to which I need draw attention. I have much pleasure in moving "That the Statement of Accounts and Balance Sheet for 1913, as presented, be received and adopted."

The President: I beg to second that motion.

Mr. F. C. Raphael: Can Mr. Hammond explain to us the entry about the Tothill-street property? The cost of the buildings and the site is £19,260; the revenue it brings in, after ground rent, rates, and taxes have been deducted, is £302, that is to say, only about 1½ per cent. There is obviously some explanation of that, and I think we should rather like to know what it is, so that it may be placed on record in the "Proceedings."

Mr. R. Hammond: We have had under consideration year after year what we should do with the Tothill-street site. We felt that it was very unwise to encourage long tenancies, and of course unless we are prepared to let the buildings on 7, 14, or 21 years' tenancies, we cannot possibly expect to get the full revenue from them. That is what has kept down our revenue from the Tothill-street property; it has been a question of policy. The Council feel—and so far the members have supported them in their policy—that it is advisable to keep that site in such a condition that if a favourable

* See p. 640.

offer came along they could realize it. In order to be able to do that our revenue has certainly suffered somewhat. I am glad to say, however, that since these Accounts were published the vacant offices on the property have been let, so that at the present moment the Council are able to report that the revenue from the Tothill-street property is the largest that we have ever obtained. It represents about £886 per annum, as against about £550 in previous years.

The resolution was put and carried unanimously.

Mr. ROGER T. SMITH : I have to propose "That the best thanks of the Institution be given to the Honorary Secretaries of the Local Sections and the Local Honorary Secretaries and Treasurers abroad for their kind services during the past year." We are all conversant with the excellent work that the Honorary Secretaries do in this country, and with the obligations that they place the Institution under for the responsible and arduous work which they carry out. The gentlemen who take up this work abroad collect the subscriptions of members, so that our thanks to them are by no means merely formal. I have much pleasure in proposing the resolution.

Mr. A. H. PREECE : I have pleasure in seconding that resolution.

The resolution was put and carried unanimously.

Mr. J. S. HIGHFIELD : I have great pleasure in proposing "That the best thanks of the Institution be given to Mr. Robert Hammond in recognition of the valuable services rendered by him as Honorary Treasurer of the Institution during the past year." I think it is unnecessary for me to say very much on the subject of this vote of thanks. We know the valuable work that Mr. Hammond has done for this Institution in looking after its accounts for so many years, and it is satisfactory to know that he has increased the balances so largely during the past year.

Mr. H. HIRST : I have much pleasure in seconding that resolution.

The resolution was put and carried with acclamation.

Mr. A. H. SEABROOK : Before proposing the vote of thanks entrusted to my care, I should like to say as Vice-Chairman of the defunct Industrial Committee that I regret that the Council cannot see its way to make itself the centre of the electrical industry, not only from the point of view of technical and scientific matters but also with regard to industrial and commercial questions. After all, whether we are professional or business men, we are all dependent on £ s. d., and whether our interests are technical and scientific or industrial and commercial, the financial factor is an essential one in our existence not only as an Institution but as individual members of the electrical industry. In my opinion it is regrettable that the Articles of Association do not seem to allow the Council to take a full share in these industrial and commercial matters. It is evident from the attendance here to-day, and the complacent attitude of the audience, that members are perfectly satisfied, unlike myself, that the Institution should confine itself entirely to the aims for which it was originally constituted. I do not wish to make any protest or complaint ; I merely give expression to my own regret in regard to the matter. I should now like to propose "That the best thanks of the Institution be accorded to the Honorary Auditors, Mr. H. Alabaster and Mr. Sidney Sharp, for their kind services during the past year."

Mr. K. EDGCUMBE : I have much pleasure in seconding the motion.

The resolution was put and carried unanimously.

Mr. W. M. MORDEY : May I also say a word that has nothing whatever to do with the resolution entrusted to me? I am one of those people who think that the influence, dignity, and usefulness of this Institution will be best maintained and increased by following the example that we have always had before us, of giving our attention to the scientific and engineering foundations of the electrical industry, rather than by attempting in any way to make it a trade association. This principle, from which the growth and strength of the Institution have sprung, is, I think, in the long run, actually the best and most helpful to the electrical industry and trade. With these remarks I should like to propose "That the best thanks of the Institution be tendered to Messrs. Bristows, Cooke, and Carpmael, for their kind services in the capacity of Honorary Solicitors to the Institution during the past year." This is a resolution which is formal in the sense that it is brought up every year, but it is not formal in any other sense. We are truly thankful to these professional gentlemen for giving us their time and their services in helping us in any matters of a legal character that come before the Institution.

Mr. E. A. NASH : I have much pleasure in seconding the resolution.

The resolution was put and carried unanimously.

The PRESIDENT : The next matter is the appointment of two Honorary Auditors. I move "That Mr. H. Alabaster and Mr. Sidney Sharp be elected Honorary Auditors for the year 1914-15."

The resolution was put and carried unanimously, and the meeting then adjourned.

INSTITUTION ANNOUNCEMENTS.

ASSOCIATE MEMBERSHIP EXAMINATION, MAY, 1914.

EXAMINERS :

English Essay	C. C. Hawkins, M.A.
Translation from French ...	H. Borns, Ph.D.
Applied Mechanics ... / *Physics*	Prof. A. W. Porter, B.Sc., F.R.S.
Chemistry	Prof. H. Jackson, F.C.S.
Electricity Supply ... / *Electric Lighting and Power*	J. F. C. Snell.
Electric Traction	Roger T. Smith.
Telegraphy	Major W. A. J. O'Meara, C.M.G.
Manufacture of Electrical Machinery	M. B. Field
Design of Electrical Machinery and Apparatus... ...	J. S. Peck.

PASS LIST.

Binyon, Basil.
Damania, Ishwarlal Bhogilal.
Goddard, Leslie Ward.
Price, Howard.
Rodwell, James Theodore.
Smith, William Balfour.
Woodward, Charles Hemlet.

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[I.P.O.E.E. = Institution of Post Office Electrical Engineers.]

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BENEVOLENT FUND.

REPORT OF THE COMMITTEE OF MANAGEMENT FOR THE YEAR 1913.

CAPITAL.

The Capital Account stood on 31st December last at £4,642 3s. od., all of which is invested.

INCOME.

The Statement of Accounts (see page 639) shows that the total receipts during 1913 were as follows :—

	£	s.	d.
Dividend on Investments... ...	153	14	4
Interest on Deposit	8	19	4
Annual Subscriptions	54	0	6
Donations of £5 and over ...	95	9	0
„ under £5	4	6	0
	£316	9	2

Contributions were received during the year from G. F. Allom, A. B. Anderson, I. Braby, M. S. Chambers, R. A. Chattock, W. C. Clinton, The Committee for the Protection of Electrical Interests, V. K. Cornish, B. Davies, Sir A. Denny, Bart., J. Devonshire, H. C. Donovan, B. M. Drake, C. V. Drysdale, D.Sc., W. Duddell, F.R.S., K. Edgcumbe, The Electrical Engineers' Ball Committee, S. Evershed, F. Gill, Dr. R. T. Glazebrook, C.B., F.R.S., B. B. Granger, F. E. Gripper, C. C. Hawkins, M.A., K. Hedges, D. Henriques, J. S. Highfield, H. W. Kolle, A. E. Levin, C. H. Merz, The Midlands Electrical Engineers' Ball Committee, L. B. Miller, W. M. Mordey, E. Parry, The Hon. Sir C. A. Parsons, K.C.B., F.R.S., W. H. Patchell, A. H. Preece, W. L. Preece, Sir W. H. Preece, K.C.B., F.R.S., W. R. Rawlings, T. Rich, R. Robertson, B.Sc., S. R. Roget, B.A., R. M. Sayers, S. Sharp, A. Siemens, C. P. Sparks, The Stearn Electric Lamp Company, A. D. Stevenson, A. Stroh, A. J. Stubbs, W. C. P. Tapper, A. P. Trotter, B.A., The "Twenty-five" Club, T. C. T. Walrond, H. W. L. Ward, J. G. Wilson-Dickson, and C. H. Wordingham.

The Committee of Management desire to acknowledge their indebtedness to the generosity of the donors and subscribers who have supported the Fund.

GRANTS.

Eleven applications for assistance were received in 1913, and the Committee, after due investigation, made grants in all the cases. Five grants were made of £10 each, four of £8, and three of £5, a total of £92 for the year.

WILDE BENEVOLENT FUND.

The Capital Account stood on 31st December last at £1,846 4s. 6d., the whole of which is invested and brings in an annual revenue of £55 17s. od.

The Balance standing to the credit of the Income Account at the end of 1913 was £304 6s. 11d.

No grant from this Fund was made during the year.

APPEAL FOR CONTRIBUTIONS.

The Committee of Management desire to call the attention of members of the Institution to the Benevolent Fund, which was formed to assist necessitous members (of all classes) or the families of deceased members. The Fund has been established nearly 25 years and the amount standing to the credit of the Capital Account is only £4,642 3s. od.

The Committee feel certain that the existence of this Fund is overlooked by a large number of the members, and they trust that it will commend itself more widely as worthy of their support.

The Committee make a special appeal to the members to put the Fund upon a substantial basis, and they specially invite them to contribute regular annual amounts.

In future it is proposed to include in the Annual Report a list of the subscriptions received during the year.

THE JOURNAL OF

The Institution of Electrical Engineers

Vol. 52. 15 JUNE, 1914. No. 236.

THE PREDETERMINATION OF THE CURRENT AND VOLTAGE AT THE RECEIVING END OF A TELEPHONE OR OTHER ALTERNATING-CURRENT LINE.*

By J. A. FLEMING, M.A., D.Sc., F.R.S., Member.

(*Paper received 9th May, 1914.*)

Although the mathematical treatment of the theory of the propagation of alternating currents along linear conductors has been very fully dealt with by various writers, and chiefly by the work of Dr. A. E. Kennelly has been reduced to a form in which it admits of easy arithmetical application in particular cases, there still seems room for some simplification in those practical cases in which an accuracy in results beyond that attainable by the slide rule is not required.

The methods here described depend partly on mechanical and partly on graphic processes, but are sufficiently good for much practical work.

Every conductor we use for telephony or for the electrical transmission of power has four primary and four secondary qualities. The four primary qualities are all scalar quantities, and the secondary are quasi-vector quantities.

The primary constants are the inductance (L), the capacity (C), the conductor resistance (R), and the dielectric conductance of the line (S), and are reckoned in henrys, farads, ohms, and mhos per mile or per kilometre of loop or double line. The first two are conservative and the last two dissipative qualities. In virtue of the first two energy is stored up in magnetic and electric form around the conductor and in the dielectric.

The four secondary qualities of the line are the vector impedance, the vector admittance, the propagation constant, and the line impedance or characteristic. These secondary quantities are denoted by the symbols *Im*, *Ad*, *P*, and *Z*. They are reckoned at so much per mile or per kilometre, and being quasi-vector quantities have size as well as position angle. The size of these vectors is denoted by putting square brackets round the symbols, viz. [*Im*], [*Ad*], [*P*], and [*Z*].

These vector quantities are defined as follows: Consider a unit length of the conductor subjected to simple harmonic electromotive force, formed of a part of a lead and the corresponding length of the return wire, this unit length being so short that the drop in voltage and current along it is graphically represented by a straight line. Then if I is the current at the centre of the unit, and V is the P.D. at the centre between its two wires, and L, C, R, and S are its constants as above, the drop in voltage along it is represented by $\mathrm{R\,I} + j\,p\,\mathrm{L\,I}$ and the drop in current by $\mathrm{S\,V} + j\,p\,\mathrm{C\,V}$, where $p = 2\,\pi \times$ frequency, and j is the sign of perpendicularity. Both these last two quantities are true vectors and denote a voltage or a current.

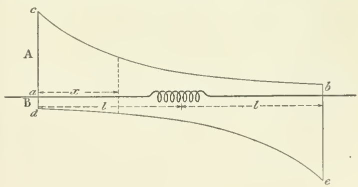


FIG. 1.

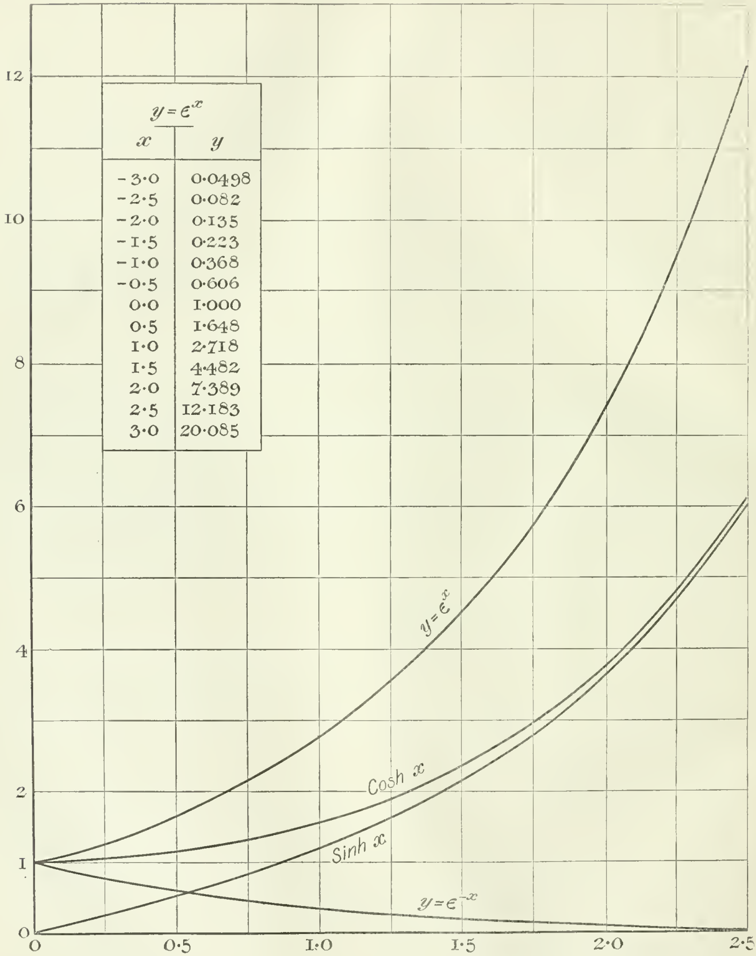
It is convenient, however, to represent them as the product of a quasi-vector and a current or voltage, viz. as $\{\mathrm{R} + j\,p\,\mathrm{L}\}\,\mathrm{I}$ and $\{\mathrm{S} + j\,p\,\mathrm{C}\}\,\mathrm{V}$, and to treat these quasi-vectors as vectors in calculations. Hence their respective sizes are $\sqrt{\mathrm{R}^2 + p^2\,\mathrm{L}^2}$ and $\sqrt{\mathrm{S}^2 + p^2\,\mathrm{C}^2}$. For unit length of the conductors we have symbols for these quantities as follows:—

$$\mathrm{R} + j\,p\,\mathrm{L} = Im, \quad \mathrm{S} + j\,p\,\mathrm{C} = Ad,$$

$$\sqrt{\mathrm{R}^2 + p^2\,\mathrm{L}^2} = [Im], \quad \sqrt{\mathrm{S}^2 + p^2\,\mathrm{C}^2} = [Ad].$$

Now the quantity P or the propagation constant is the geometric mean of the vector impedance Im and the

* The subject-matter of this Paper is based on a lecture delivered by the author on 28th April, 1914, to the Manchester Local Section.



$y=\epsilon^{x}$

x	y
−3·0	0·0498
−2·5	0·082
−2·0	0·135
−1·5	0·223
−1·0	0·368
−0·5	0·606
0·0	1·000
0·5	1·648
1·0	2·718
1·5	4·482
2·0	7·389
2·5	12·183
3·0	20·085

FIG 2.

vector admittance Ad, or $P = \sqrt{Im} . \sqrt{Ad}$, while the line characteristic or impedance Z is the quotient of the same quantities, or $Z = \sqrt{Im}/\sqrt{Ad}$.

Returning then to the unit length of the circuit we can express the drop in voltage and current as follows :—

Drop in voltage = Im × *Mean current in it.*
Drop in current = Ad × *Mean voltage across it.*

Hence the drop in the drop in voltage, or as it may be called the (drop)² in the voltage, is given by the equation—

Drop in the drop in voltage
= $Im \times Ad$ × *Mean voltage across it.*

Let us consider how this can be graphically represented.

If we draw an exponential or logarithmic curve, that is a curve whose equation is $y = \epsilon^{Px}$, where ϵ is the base of the Napierian logarithms, it is clear that the slope of the curve at any point is proportional to the ordinate, or is equal to $P\,y$. Also the slope of the slope or rate of change of slope is proportional to the ordinate and equal to $P^2 y$. Accordingly it is evident that if an alternating E.M.F., V_1, is applied at any point in an infinitely long cable the voltage V at any other point at a distance x will be represented by the exponential expression $V = V_1 \epsilon^{-Px}$. In practice, however, all our cables are of finite length, and we have moreover to take into account the effect of the receiving instrument at the end.

Consider then a cable of length l having a receiving instrument of impedance $R_2 + j\,p\,L_2$ placed at the receiving end, and an impressed electromotive force V_1 applied at the sending end. We may consider that the cable is laid out straight (see Fig. 1) and that the applied E.M.F. is represented by a positive potential at one point and an equal negative potential at another point placed at a distance $2\,l$ in an infinite cable. The receiving instrument is represented by the coil placed in the centre. Then each potential falls along the cable according to an exponential law, and the potential V at any distance x from the sending end is seen to be the algebraic sum of two factors, or—

$$V = A\,\epsilon^{-Px} + B\,\epsilon^{+Px} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

It is now convenient to substitute for these exponential expressions their equivalent in hyperbolic functions.

If we draw two exponential curves, one rising and the other falling and both starting from an ordinate $y = 1$ at $x = 0$, these curves have ordinates $y = \epsilon^x$ and $y = \epsilon^{-x}$ at any abscissa x (see Fig. 2). If we take half the sum and half the difference of the ordinates at any abscissa, these values are called respectively the hyperbolic cosine and the hyperbolic sine, and are represented by—

$$\cosh x = \tfrac{1}{2}(\epsilon^x + \epsilon^{-x}) \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and—

$$\sinh x = \tfrac{1}{2}(\epsilon^x - \epsilon^{-x}) \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Hence—

$$\epsilon^x = \cosh x + \sinh x \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\epsilon^{-x} = \cosh x - \sinh x \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Substituting these functions for ϵ^{+Px} and ϵ^{-Px} in (1), we have—

$$V = (A + B)\cosh Px - (A - B)\sin Px \quad . \quad . \quad . \quad (6)$$

It is clear that when $x = 0$ we have $V = V_1$, and also $\cosh Px = 1$ and $\sinh Px = 0$; therefore we have $V_1 = A + B$.

Again the current I in any unit of length of the cable is obtained by dividing the drop in potential along it by the vector impedance of the unit.

Hence we have—

$$I = \frac{P}{R + j\,p\,L}\left\{A\,\epsilon^{-Px} - B\,\epsilon^{+Px}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$I = \frac{1}{Z}\left\{(A - B)\cosh Px - (A - B)\sinh Px\right\} \quad . \quad . \quad (8)$$

and when $x = 0$ we have $I = I_1$; therefore $Z\,I_1 = A - B$.

Substituting the values $A + B = V_1$ and $A - B = Z\,I_1$ in Equations (6) and (8), and also bearing in mind that the receiving instrument impedance $Z_r = V_2/I_2$, where V_2 and I_2 are the voltage and current at the receiving end at which $x = l$, it is easy to see that we obtain the equations—

$$V_2 = V_1 \cosh P\,l - I_2\,Z \sinh P\,l \quad . \quad . \quad . \quad . \quad (9)$$

$$I_2 = I_1 \cosh P\,l - \frac{V_1}{Z} \sinh P\,l \quad . \quad . \quad . \quad . \quad (10)$$

Separating the variables and putting $V_2 = I_2 Z_r$, we obtain the final equations—

$$V_1 = V_2 (\cosh P\,l + \frac{Z}{Z_r} \sinh P\,l) \quad . \quad . \quad . \quad (11)$$

$$I_1 = I_2 (\cosh P\,l + \frac{Z_r}{Z} \sinh P\,l) \quad . \quad . \quad . \quad (12)$$

These last equations enable us to find the values of V_2 and I_2 from those of V_1 and I_1 when we know the value of the complex factor in the bracket.

In applying the above formulæ (11) and (12) in numerical calculations in any given case the chief difficulty which arises is that the addition, multiplication, and division to be carried out in reckoning the factor in the bracket are vector operations, and the quantities themselves, viz. Z_r, Z, $\cosh P\,l$, and $\sinh P\,l$, are complex quantities. If two complex quantities are given in the form $a + j\,b$, $c + j\,d$, it is an easy matter to add them, for their sum is $(a + c) + j\,(b + d)$. If, however, we have to divide or multiply them they have to be converted first to the equivalent forms—

$$\sqrt{a^2 + b^2}\,\underline{/\tan^{-1}\frac{b}{a}} \quad \text{and} \quad \sqrt{c^2 + d^2}\,\underline{/\tan^{-1}\frac{d}{c}}.$$

These are troublesome arithmetical operations and require also a table of natural tangents. To facilitate this transformation the author has devised a vector calculating rule made as follows :—

Two boxwood scales about 1·5 metres long have their edges divided into centimetres and millimetres, and are hinged together at the zero ends. A quadrant protractor is attached to one rule so as to show at a glance the angle which the inner edges make with each other when the rule is opened (see Fig. 3). A T-square having one edge graduated in centimetres and millimetres slides along one of the rules. Hence if we are given a complex quantity in the form $300 + j\,400$ we can slide the T-square along so as

to set off on one rule an intercept of 300 mm. We then open the rule so that the other arm sets off an intercept of 400 mm. on the T-square edge, and we see at once that the hypothenuse of the triangle is 500 mm. and the slope of the rule is $\tan^{-1}\frac{4}{3} = 53° 7'$.

By the aid of the rule we can then convert the expressions for vectors in the form $a + j\,b$ and $\sqrt{a^2+b^2}\big/\tan^{-1}\frac{b}{a}$ into one another numerically with great ease.

To obtain the square root of a complex quantity given in the form $\sqrt{R + j\,p\,L}$ we have to convert $R + j\,p\,L$ to the form $\sqrt{R^2 + p^2 L^2}\big/\tan^{-1}\frac{p\,L}{R}$, and then to take the square root of the size and halve the angle. Hence—

$$\sqrt{R + j\,p\,L} = (R^2 + p^2 L^2)\ \big/\tfrac{1}{2}\tan^{-1}\frac{p\,L}{R}.$$

Accordingly when we are given the primary constants of a cable, viz. R, L, S, and C, and also p ($= 2\,\pi \times$ frequency, n), we can calculate the value of the line impedance, $Z = \sqrt{R + j\,p\,L}/\sqrt{S + j\,p\,C}$, by finding the vector expressions for $\sqrt{Im}$ and $\sqrt{Ad}$ as above and then dividing the size of the first by that of the second and subtracting the phase angles. The arithmetical operations consist in finding the numerical value of $Z = \sqrt{Im}/\sqrt{Ad}$ or of $\sqrt{R + j\,p\,L}/\sqrt{S + j\,p\,C}$ and its slope, which is equal to $\left(\frac{R^2 + p^2 L^2}{S^2 + p^2 C^2}\right)^{\frac{1}{4}} /\tfrac{1}{2}\tan^{-1} p\,L/R - \tfrac{1}{2}\tan^{-1} p\,C/S$. This is vastly facilitated by the use of the above rule when only a moderate degree of accuracy is required.

Thus, if we are given the line constants of a standard telephone cable for which R = 88 ohms, L = 0·001 henry, C = 0·05 microfarad, $S = 5 \times 10^{-6}$ mho, all per loop mile, and if $p = 2\,\pi\,n = 5{,}000$, we find at once—

$$Im = 88 + j\,5 = 88{\cdot}1\,/3°\ 15';$$

and—

$$Ad = \frac{5}{10^6} + j\,\frac{250}{10^6} = \frac{1}{4010}\,/88°\ 51'.$$

Hence—

$$Z = \frac{\sqrt{Im}}{\sqrt{Ad}} = 593\ |\ 42°\ 48'.$$

In these calculations, if one of the above-described vector calculating rules is not at hand, a single four-figure table of squares and square roots and a table of natural tangents, such as that of J. T. Bottomley, will be found of great assistance.

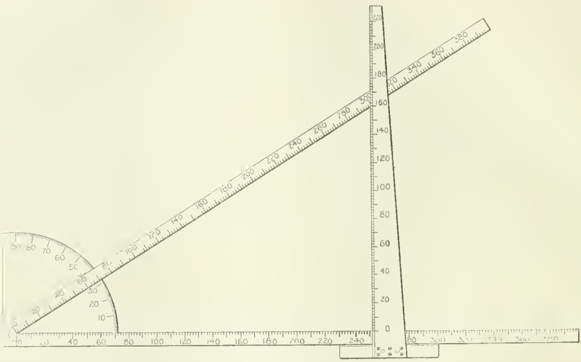


FIG. 3.—Vector Calculating Rule. (Fleming.)

It is therefore quite easy to find the vector value of Z_r/Z or its reciprocal, when we are given the impedance of the receiving instrument and the constants of the line.

In the next place we have to find the value of cosh $P\,l$ and sinh $P\,l$. Since $P = \sqrt{Im}\,.\sqrt{Ad}$, we can obtain the value of P at once in the form S/θ, and by the aid of the rule convert it to the form $P = a + j\,\beta$. Thus, for the same standard cable $P = \sqrt{Im}\ .\ \sqrt{Ad}$, or—

$$P = \sqrt{\frac{88{\cdot}1}{4000}}\ /46°\ 3'\ 30'' = 0{\cdot}148\,/46°\ 3'\ 30''.$$

Converting this back into the form $a + j\,\beta$ by the aid of the vector rule, we find it is equal to $0{\cdot}103 + j\,0{\cdot}104$. Hence $a = 0{\cdot}1$ and $\beta = 0{\cdot}1$ nearly. If then the length of the cable is given, say 20 miles, we have $P\,l = 2 + j\,2$.

We have in the next place to find the value of cosh $P\,l$ and sinh $P\,l$. These quantities are both vectors because $P\,l = a\,l + j\,\beta\,l$ is a vector.

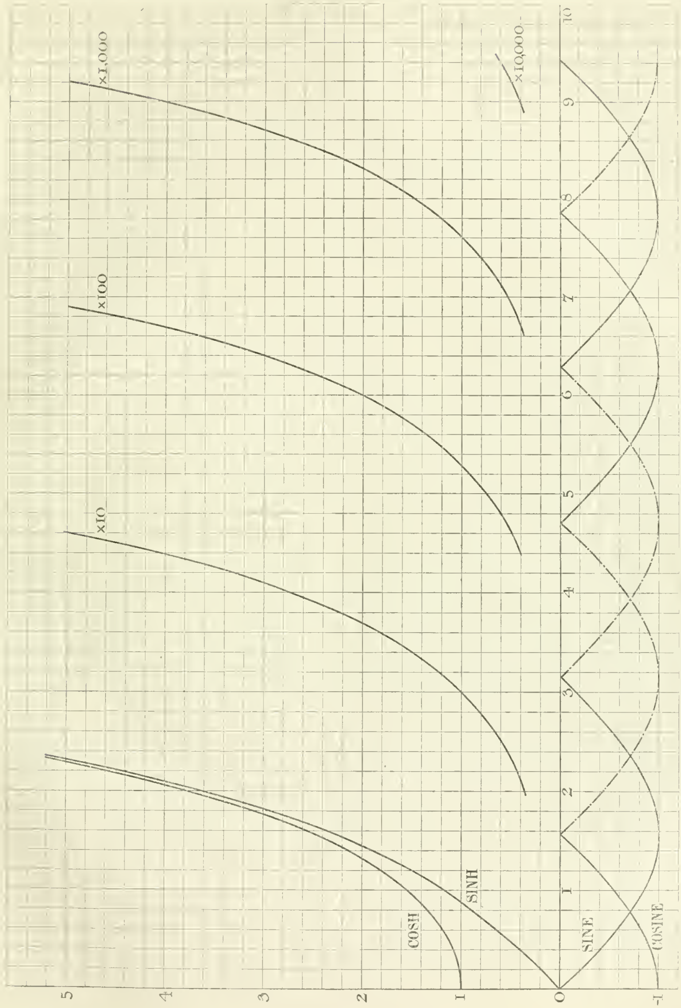


FIG. 4.—Graphical Delineation of the Circular and Hyperbolic Sines and Cosines for Arguments 0 to 10.

Circular and Hyperbolic Functions of Radians.

Angle *u* in Circular Measure	Sine *u*	Cosine *u*	Sinh *u*	Cosh *u*
0	0	1	0	1
0·1	0·09983	0·99500	0·10017	1·00500
0·2	0·19867	0·98007	0·20134	1·02007
0·3	0·29552	0·95534	0·30452	1·04534
0·4	0·38942	0·92106	0·41075	1·08107
0·5	0·47943	0·87758	0·52110	1·12763
0·6	0·56464	0·82534	0·63665	1·18547
0·7	0·64422	0·76484	0·75858	1·25517
0·8	0·71736	0·69671	0·88811	1·33743
0·9	0·78333	0·62161	1·02652	1·43309
1·0	0·84147	0·54030	1·17520	1·54308
1·1	0·89120	0·45360	1·33565	1·66852
1·2	0·93204	0·36236	1·50946	1·81066
1·3	0·96356	0·26750	1·69838	1·97091
1·4	0·98545	0·16997	1·90430	2·15090
1·5	0·99749	0·07074	2·12928	2·35241
1·57	1·00000	0·0000	2·29930	2·50735
1·6	0·99957	−0·02920	2·37557	2·57746
1·7	0·99167	−0·12880	2·64563	2·82832
1·8	0·97383	−0·22728	2·94217	3·10747
1·9	0·94627	−0·32343	3·26816	3·41773
2·0	0·90926	−0·41619	3·62686	3·76220
2·1	0·86316	−0·50493	4·02186	4·14431
2·2	0·80845	−0·58858	4·45711	4·56791
2·3	0·74564	−0·66635	4·93696	5·03722
2·4	0·67539	−0·73743	5·46623	5·55695
2·5	0·59840	−0·80120	6·05020	6·13229
2·6	0·51542	−0·85694	6·69473	6·76900
2·7	0·42730	−0·90411	7·40626	7·47347
2·8	0·33396	−0·94225	8·19192	8·25273
2·9	0·23818	−0·97098	9·05956	9·11458
3·0	0·14100	−0·99000	10·0179	10·0677
3·1	0·04159	−0·99913	11·0765	11·1215
3·1416	0·0000	−1·0000	—	—
3·2	−0·05837	−0·99830	12·2459	12·2866
3·3	−0·15734	−0·98746	13·5379	13·5747
3·4	−0·25555	−0·96677	14·9654	14·9987
3·5	−0·35090	−0·93643	16·5426	16·5728
3·6	−0·44261	−0·89673	18·2855	18·3128
3·7	−0·52991	−0·84806	20·2213	20·2360
3·8	−0·61194	−0·79090	22·3394	22·3618
3·9	−0·68710	−0·72657	24·6911	24·7113
4·0	−0·75687	−0·65358	27·2899	27·3082
4·1	−0·81834	−0·57474	30·1619	30·1784
4·2	−0·87163	−0·49106	33·3357	33·3507
4·3	−0·91620	−0·40071	36·8431	36·8567
4·4	−0·95160	−0·30727	40·7190	40·7316
4·5	−0·97752	−0·21080	45·0030	45·0141
4·6	−0·99370	−0·11216	49·7371	49·7472
4·7	−0·99992	−0·01240	54·9690	54·9781
4·712	−1·0000	0·00000	—	—
4·8	−0·99616	0·08748	60·7511	60·7593
4·9	−0·98245	0·18649	67·1412	67·1486

Angle *u* in Circular Measure	Sine *u*	Cosine *u*	Sinh *u*	Cosh *u*
5·0	−0·95895	0·2[illegible]64	74·2032	74·2099
5·1	−0·92582	0·37707	82·0079	82·0140
5·2	−0·88346	0·46850	90·6333	90·6388
5·3	−0·83228	0·55136	100·167	100·171
5·4	−0·77275	0·63473	110·701	110·705
5·5	−0·70527	0·70[illegible]4	122·344	122·348
5·6	−0·63128	0·[illegible]7556	135·211	135·215
5·7	−0·55070	0·83470	149·432	149·435
5·8	−0·46462	0·88553	165·148	165·151
5·9	−0·37389	0·92748	182·517	182·520
6·0	−0·27914	0·96017	201·713	201·716
6·1	−0·1[illegible]218	0·98325	223	223
6·2	−0·08310	0·99654	246·5	246·5
6·283	0·0000	1·0000	—	—
6·3	0·01679	0·99986	272·5	272·5
6·4	0·11652	0·99318	301	301
6·5	0·21510	0·97658	332·5	332·5
6·6	0·31151	0·95024	367·5	367·5
6·7	0·40480	0·91439	406	406
6·8	0·49410	0·86941	449	449
6·9	0·57842	0·81575	497·5	497·5
7·0	0·65700	0·75390	550	550
7·1	0·72897	0·68455	606	606
7·2	0·79366	0·60836	670	670
7·3	0·85042	0·52608	740	740
7·4	0·89870	0·43856	817	817
7·5	0·93799	0·34667	905	905
7·6	0·96793	0·25130	997·5	997·5
7·7	0·98811	0·15340	1105	1105
7·8	0·99854	0·05400	1220	1220
7·9	0·99894	−0·04593	1348	1348
8·0	0·98936	−0·14548	1490	1490
8·1	0·96990	−0·24353	1646	1646
8·2	0·94075	−0·33915	1820	1820
8·3	0·90220	−0·43136	2010	2010
8·4	0·85460	−0·51927	2223	2223
8·5	0·79852	−0·60200	2457	2457
8·6	0·73442	−0·67870	2711	2711
8·7	0·66295	−0·74860	3001	3001
8·8	0·58495	−0·81108	3316	3316
8·9	0·50102	−0·86542	3666	3666
9·0	0·41212	−0·91112	4057	4057
9·1	0·31911	−0·94770	4475	4475
9·2	0·22300	−0·97482	4947	4947
9·3	0·12447	−0·99222	5467	5467
9·4	0·02480	−0·99969	6043	6043

Bearing in mind the exponential values of $\cosh x$ and $\sinh x$ and $\cos x$ and $\sin x$ as follows:—

$$\cosh x = \varepsilon^{x}/2 + \varepsilon^{-x}/2, \quad \sinh x = \varepsilon^{x}/2 - \varepsilon^{-x}/2,$$
$$\cos x = \varepsilon^{jx}/2 + \varepsilon^{-jx}/2, \quad \sin x = \varepsilon^{jx}/2j - \varepsilon^{-jx}/2j,$$

it is easy to show that—

$$\cosh(\alpha l + j\beta l) = \cosh\alpha l \cos\beta l + j \sinh\alpha l \sin\beta l,$$
$$\sinh(\alpha l + j\beta l) = \sinh\alpha l \cos\beta l + j \cosh\alpha l \sin\beta l.$$

If then we are given the values of αl and βl it is a simple matter to find the values of $\cosh Pl$ and $\sinh Pl$ from curves delineated in the chart (Fig. 4) at the end of this paper.

In these curves the author has graphically represented the circular and hyperbolic sine and cosine curves plotted in terms of radians as horizontal abscissæ set off along a base line. To distinguish the positive from the negative values of the circular sine and cosine the parts of the curves which have negative values of the ordinates are shown as dotted lines. The values from which the curves are plotted are given in the Table on the opposite page. The hyperbolic sine and cosine are also plotted to the same arguments from the calculated values in the same Table.

Since, however, these last curves rise up continuously, it is convenient to divide the ordinates by 10 as soon as the first branch of the curve reaches the top of the paper. When the second branch rises to a similar height we divide again by 100, and in a third branch by 1,000. In this way we can plot curves for $\cosh x$ and $\sinh x$ up as high as $\cosh 9$ and $\sinh 9$ on squared paper of moderate size.

The curves as actually shown in Fig. 4 are on rather too small a scale to enable values to be read off with much accuracy. The reader can, however, easily re-draw the curves on good squared paper divided into centimetres and millimetres on a larger scale, taking the calculated values from the Table and drawing the curves in the manner shown in Fig. 4. This large scale chart will then enable the values of the functions to be read off to an accuracy of the second or third place of decimals.

Suppose, then, we require the value of $\cosh(2 + j2)$. We look out on these curves the value of $\cosh 2$, $\sinh 2$, $\cos 2$, and $\sin 2$, which are the respective ordinates of the four curves to argument 2. We find $\sinh 2 = 3{\cdot}63$, $\cosh 2 = 3{\cdot}77$, $\sin 2 = 0{\cdot}91$, and $\cos 2 = -0{\cdot}42$. Hence—

$$\cosh(2 + j2) = -1{\cdot}583 + j\,3{\cdot}303,$$
$$\sinh(2 + j2) = -1{\cdot}525 + j\,3{\cdot}431.$$

The vector rule shows us at once that—

$$-1{\cdot}525 + j\,3{\cdot}431 = 3{\cdot}74\,/\underline{113^\circ\ 45'},$$

If, then, the receiving instrument at the end of the line is a 60-ohm Bell telephone, for which—

$$Z_r = 134 + j\,91 = 162\,/\underline{34^\circ\ 15'},$$

we find immediately that for 20 miles of this standard telephone cable Equation (11) becomes—

$$\frac{V_1}{V_2} = (-1{\cdot}583 + j\,3{\cdot}303) + \frac{593\ \overline{|\,42^\circ\ 48'}}{162\ \underline{|\,34^\circ\ 15'}}\,3{\cdot}74\,/\underline{113^\circ\ 45'}.$$

Now $593 \times 3{\cdot}74/162 = 13{\cdot}7$, and—

$$113^\circ\ 45' - 42^\circ\ 48' - 34^\circ\ 15' = 36^\circ\ 42',$$

and $$13{\cdot}7\,/\underline{36^\circ\ 42'} = 11{\cdot}0 + j\,8{\cdot}2.$$

Hence $$V_1/V_2 = 9{\cdot}5 + j\,11{\cdot}5 = 14{\cdot}9\,/\underline{50^\circ\ 30'}.$$

Accordingly if 10 volts were applied at the sending end, the voltage V_2 at the receiver terminals would be $10/14{\cdot}9 = 0{\cdot}66$ volt. The current through the telephone would be 0·66 divided by the telephone impedance, which is 162 ohms. Hence $I_2 = 660/162 = 4$ milliamperes. It will be seen, therefore, that for approximate calculations, such as may be necessary in getting out general specifications or predeterminations for proposed telephone lines, the vector rule and curves here described will prove very useful. When greater accuracy is required tables of hyperbolic functions of complex arguments, such as those recently published by Dr. A. E. Kennelly, through the Harvard University Press, will be requisite.

For preliminary rough calculations the use of the above described vector rule in conjunction with a slide rule immensely economizes time. The author has arranged with Messrs. W. F. Stanley & Co., of Holborn, London, to make and supply this vector calculating rule.

THE BONECOURT BOILER.

By C. D. McCourt.

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It is a recognized fact that gas-fired boilers as a class are less efficient than boilers which are fired with solid fuel. The advent of the Bonecourt boiler reversed this state of affairs, this type of boiler being more efficient than any coal-fired boiler hitherto constructed. In order to show to what this is due, the author proposes to consider first of all the operation of ordinary or flame-fired boilers contrasted with that of the Bonecourt boiler.

Gas-fired boilers of the ordinary type might be described as steam generators which are flame-fired, while a Bonecourt boiler is a steam generator which is fired with fuel in a fluid state in such a manner that little or no flame is produced during the combustion. This difference is a fundamental and important one. In the flame-fired boiler a considerable free space is required for the proper development of the flame. If the flame, consisting as it does of a succession of gaseous envelopes of various oxygen contents, comes into contact prematurely with a water-cooled surface, combustion is hindered and products of incomplete combustion arise. In flame-fired boilers, therefore, it is necessary so to arrange the construction that a sufficiently large space is provided for the free development of flame.

In the Bonecourt boiler, on the other hand, complete combustion is obtained without the development of flame. Combustible gas and air in the proportions theoretically required for complete combustion are intimately mixed together so as to produce a homogeneous gaseous medium, and this gaseous medium, containing in itself all the elements required for complete self-combustion, is delivered at a high speed into a bed of refractory material, on the surface of which combustion takes place flamelessly. Such a mixture of gas and air is explosive, hence the necessity for supplying the mixture to the granular bed at a high speed—a speed, in fact, which is greater than the speed at which the mixture will ignite in a backward direction. The bed is maintained incandescent by the continued combustion of the gaseous mixture, and complete combustion of the gas employed is ensured by the incandescence of the bed into which the mixture is passed. It is found that if combustion be brought about in this way the proximity of water-cooled surfaces has no hindering effect on the combustion, and it is possible so to arrange the granular bed in relation to the water space as to obtain the maximum possible proximity of the water to the heat zone. It will be seen that we have here the elements of construction which are required for designing boilers of high evaporative power.

In applying these principles to the construction of steam generators it is possible to employ either a fire-tube or a water-tube type of design. It is more convenient, however, to pack the interiors of tubes with refractory granules than to surround water-tubes with these granules. Hence, the multitubular type of boiler is the one to which this system has first been applied.

Describing first of all in general terms any typical Bonecourt boiler installation, the boiler consists of a multitubular drum the tubes of which are fitted with a refractory packing that serves to promote rapid combustion. The combustible gas is delivered to the seat of combustion in the packed tubes in a state of intimate admixture with air. Just so much air is present in the mixture as will suffice for the complete oxidation of the fuel, excess of air being avoided. The author cannot too strongly emphasize the fact that this mixture of gas and air, in the proportions theoretically required for complete combustion, is a homogeneous mixture, containing in itself all the elements necessary for complete combustion. The mixture is delivered at a high speed into boiler tubes packed with refractory material of such a kind as to leave interstices through which the gases can flow. A suitable packing for tubes of relatively small size, 3 in. in bore for example, consists of firebrick crushed and meshed so as to produce fragments of about 1 in. in diameter. These fragments, while being fairly regular in size, are irregular in shape, and leave interstices which in the aggregate amount to the same volume as that of the fragments themselves.

The boiler tubes are closed at their entrance ends by fireclay plugs through holes in which the gaseous mixture passes. These holes are of such cross-section that the speed of flow of the gaseous mixture is greater than the speed of ignition of the mixture. This ensures that combustion does not take place prior to the mixture gaining admission to the granules in the tubes.

In order to cause the gaseous mixture to pass through the apertures in the fireclay plugs with the required speed, and to enable the combustion products to overcome the resistance offered by the refractory packing in the boiler tubes, it is necessary to maintain a certain difference of pressure between the opposite ends of the boiler tubes. The amount of this pressure difference required will depend in the main on the rate of evaporation desired. In general, a pressure difference of 15 in. water gauge will suffice for an evaporation of 20 lb. of water from and at 212° F. per sq. ft. of heating surface per hour. With an increase of the pressure difference the evaporation likewise increases, and it is found that the evaporation produced is proportional to the square root of the pressure difference which is applied.

The necessary pressure difference can be obtained in one of two ways, either by supplying the gaseous mixture to the boiler tubes under a positive pressure, for which purpose a fan for blowing the gas and a fan for blowing the air are required, or by drawing away the products of combustion at the exit ends of the boiler tubes by means of a single fan. In either case the amount of pressure or suction, as the case may be, to produce a given evaporation is the same.

The lantern slide shows a view of a Bonecourt boiler installed at the Skinningrove Iron Works and fed with coke-oven gas. This boiler is worked on the suction principle, a fan at the outlet end of the plant drawing the products of combustion through the system under a suction of about 15 in. water gauge. The plant comprises a boiler shell

10 ft. in diameter and 4 ft. long, a feed-water heater 4 ft. 6 in. in diameter and 18 in. long, and an electrically-driven fan. The boiler shell is provided with 110 tubes, each 4 ft. long and 3 in. in bore, charged with refractory material, while the feed-water heater is furnished with 100 tubes 3 in. in bore and 18 in. long, and similarly charged. The gas is supplied to the boiler under the normal pressure existing in the coke-oven main, namely 2 or 3 in. water gauge, and is drawn under suction through the boiler tubes in a state of intimate admixture with air, which is drawn by the same suction from the surrounding atmosphere.

As a description of this plant and its performance has already appeared in the technical Press* the author does not propose to describe it here, except to say that its performance has fully come up to expectations in every way, an efficiency of 92·7 per cent being obtained when evaporating 14·1 lb. of water from and at 212° F. per sq. ft. of heating surface per hour. That the working of the boiler is deemed satisfactory from a practical point of view by those in the best position to judge is proved by the fact that after the plant was taken over a duplication of the plant was ordered by the purchasers, and the second unit will shortly be in operation.

A plant identical with the Skinningrove plant has been erected at the works of Messrs. Friedrich Krupp & Co. in Germany, and the author understands that the official test, although the results are not yet published, has afforded equally satisfactory figures.

Leaving now the particular case of the plant just described, the author proposes to consider the general case of what takes place in a boiler tube of any Bonecourt boiler. A homogeneous mixture of combustible gas and air passes into the bed of refractory granules with which the tube is charged. Combustion there takes place, and as the mixture which burns is a highly explosive one, combustion is completed for all practical purposes instantaneously, and the granules are maintained incandescent as previously mentioned.

The temperature in the granular packing at the entrance or firing end of the tube will approximate to the calorific intensity of the gas employed. When burning coal-gas or coke-oven gas, the temperature at this point is in the neighbourhood of 1,800° C. It must be understood that this is the temperature in the centre of the cross-section, and that the temperature of the granules in contact with the tube surface is very much lower. The temperature of the inner surface of the tube itself is only some 20° C. higher than that of the surface in contact with the water. The granular packing, then, is red-hot or white-hot at the firing end, but its temperature decreases very rapidly along the tube. In the centre the temperature is a dull red heat, while at the exit end the temperature is about 250° C.

It is necessary to form a clear picture of the functions performed by the granular packing. In the first place, the red-hot granules serve to ensure absolute completion of combustion even in the absence of any air in excess of the theoretical requirements. Secondly, they radiate heat to the sides of the containing tube walls, thus largely accounting for the high rate of heat transmission obtained. Thirdly, the granules, even in that part of the tube where the temperature is so low as to prevent heat being communicated to any notable extent by radiation, serve to baffle the combustion products and hurl them repeatedly and with violence against the tube walls. This last phenomenon is one that is often not sufficiently appreciated. If hot gases flow through a water-cooled tube, they communicate their heat to the water very sluggishly. If, however, any device is employed which will cause the hot gases to impinge on the tube surface, heat transmission is greatly increased. To account for this it has been suggested that in normal boiler practice a non-conducting film of cold gases clings tenaciously to the tube surface or boiler plate. If that be so, the effect of the granular packing must be to destroy, by abrasion as it were, this film of cold gases, intimate contact of the hot gases with the tube surface being then obtained.

Considerable latitude is permissible in the design and construction of Bonecourt boilers. A selection can be made as regards the dimensions of the drum and the diameter of the boiler tubes. The length of the tubes (and therefore of the containing drums) can vary from 3 ft. to 12 ft. Messrs. Bonecourt Surface Combustion, Ltd., have installed or are installing boiler plant of which the tubes and shells range within these limits, while they have carried out experiments with tubes 24 ft. long, and it is possible that in some cases tubes even as large as this will be employed in practice.

For a given kind of packing in the tubes, there must be preserved a definite ratio between the length and bore of the tubes in order to obtain sufficient cooling of the combustion gases. Thus, when tubes of 3-in. bore are employed the length is generally 3 ft. or 4 ft. In this case the ratio of length to bore is 12 to 1 or 16 to 1. If it be desired to employ longer tubes of the same bore, this may be done without sacrificing considerations of economy by employing a packing material of a more open nature in the tubes. It is clear that the more closely the refractory material is disposed in the tubes, the steeper will be the temperature gradient from end to end. By suitably selecting the packing for the tubes we have found that we can very effectively employ in boiler construction tubes ranging from 3 in. in bore and 3 ft. long to tubes 12 in. in bore and 24 ft. long. It will be seen that this affords great latitude in boiler design, enabling boiler shells to be made from 3 ft. to 24 ft. in length and of any desired diameter.

It will be gathered from what has already been said that the nature of the packing material in the boiler tubes is a matter of importance. Where a close packing is desired, as for example in tubes in which the ratio of length to bore is relatively small, refractory fragments of about 1 in. in diameter may be employed. Where the ratio of length to bore is greater, larger fragments can be used—for example, up to 3 in. in diameter. If a still more open packing is wanted, the granules may be lengthened until they stretch right across the tube, and arranged in a staggered manner so as to effect the necessary baffling of the gases.

Now with regard to the utilization of the heat developed in a Bonecourt boiler installation. In any form of steam generator the possible losses are :—

1. Loss of heat due to part of the fuel escaping combustion, or being only partially burned.

2. Heat carried away in the form of heated air, being air supplied in excess of the theoretical requirement.

3. Heat carried away in the products of combustion leaving the system.

* *Electrician*, vol. 71, p. 171, 1913.

4. Loss of heat by so-called radiation from the exterior of the system.

Of these four possible sources of loss, Nos. 1 and 2 are for all practical purposes completely eliminated from the Bonecourt system. There is no heat loss due to part of the fuel escaping combustion or being only partially burned. Repeated analyses of the products of combustion from Bonecourt boilers have shown that in every case the combustion is complete so long as sufficient air is admitted to satisfy the theoretical requirement. Neither is there any appreciable heat loss due to air supplied in excess of the theoretical requirement entering the system at a low temperature and leaving it at a higher temperature, because it is found that it is not necessary to supply air in excess of the theoretical requirement in order to ensure complete combustion. This is in striking contrast to the normal practice with regard to coal-fired boilers, where an excess of air amounting to from 50 to 100 per cent of the theoretical requirement is necessitated, failing which there would result a very incomplete combustion of the fuel.

The heat carried away in the products of combustion leaving the system is very nearly proportional, for low temperatures at all events, to the temperature of the products. The specific heats of carbon-dioxide, nitrogen, water vapour, and oxygen being known over a wide range of temperature, the actual heat losses occasioned by gases of known composition leaving the system at a known temperature can be calculated.

Inasmuch as the ratio of air to gas burned in the Bonecourt system can be regulated to a great nicety, so as to correspond almost exactly with the theoretical requirements, and inasmuch as the gas is completely burned, thus avoiding on the one hand any appreciable content of oxygen in the flue gases, and avoiding on the other hand the presence of any carbon-monoxide or other unburned gas in the flue gases, it is possible to construct for any Bonecourt boiler installation a very clean heat balance-sheet, and it is therefore worth while considering the unavoidable losses from the standpoint of theory in order to be in a position to determine how closely the performance of any given installation approaches to the theoretically obtainable ideal.

To this end the author proposes to consider the case in which the gas burned is producer gas made in an ammonia-recovery plant and analysing:—

	Per cent
Carbon-dioxide	17·0
Carbon-monoxide	11·0
Hydrogen	26·0
Methane	2·7
Nitrogen	43·3
	100·0

the net calorific value of this gas being 140 B.Th.U.'s per cubic foot N.T.P.

Assuming that this gas is burned with the theoretical requirement of air, 1 cub. ft. N.T.P. of the gas will yield:—

Carbon-dioxide	0·31 cub. ft. N.T.P.
Water vapour	0·31 „ „
Nitrogen	1·33 „ „
	1·95 „ „

Calculating from the known specific heats of the gaseous constituents, we are able to express the sensible heat (measured from a *datum* line of 0° C.) of the products of combustion at different temperatures as a percentage of the calorific value of the gas burned. The results obtained are shown in the form of a curve in Fig. 1. By means of this curve it is possible to read

FIG. 1.—Combustion Products of Producer Gas. Curve showing sensible heat measured from 0° C. expressed as a percentage of the net calorific value of the gas.

off at a glance the heat lost in the combustion products from a Bonecourt boiler installation once the temperature of the chimney gases is known. The heat contributed to the system is known in terms of the volume and calorific value of the gas burned, and the heat usefully employed in terms of the weight of water evaporated. The radiation loss from the system is then readily found by the difference.

In a Bonecourt boiler installation the combustion products leave the system at a temperature of about 110° C. where a feed-water heater is employed, and the amount of heat carried away by the waste gases is therefore very small. Owing to the high evaporative power, and therefore the compactness of the plant, the radiation loss only amounts to about 2 per cent, and in some cases is considerably less. It therefore follows that the figures which ought to be obtained, and are obtained from Bonecourt boilers fired with coal-gas or coke-oven gas, yield a heat balance sheet of which the following may be taken as typical:—

	Per cent
Heat utilized in steam generator	95
Heat lost in combustion products ...	3
Heat lost in radiation	2
Heat originally available in gas burned ...	100

while in the case of producer gas the expected heat balance-sheet would be :—

	Per cent
Heat utilized in steam generation ...	94
Heat lost in combustion gases	4
Heat lost in radiation	2
Heat originally available in gas burned ...	100

A battery of three Bonecourt boilers for burning ammonia-recovery producer gas is at present being installed in the works of an important firm in this country, and it is expected that in about two months the plant will be in operation. The steam developed by the boilers is to be used first of all for driving steam turbines, the exhaust from which is to be passed into the gas plant at a gauge pressure of about 3 lb. per square inch. The quantity of steam required will vary in accordance with the demands of the gas plant, but the maximum for the present expectations is at the rate of 22,000 lb. of steam per hour at a gauge pressure of 80 lb.

The boiler-house, which measures internally 38 ft. × 50 ft., is designed to accommodate three Bonecourt boilers, each with a normal full-load capacity of 11,000 lb. per hour, and all auxiliary apparatus. The general lay-out of this apparatus is shown in Fig. 2. It should be noted in connection

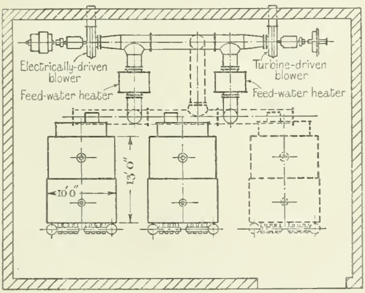

FIG. 2.

with this lay-out that as plenty of space was available for the equipment, generous margins have been allowed and no attempt has been made to place the boiler equipment in the smallest available space. It is interesting to note that, had the necessities of space demanded it, this same steaming capacity could have been condensed into a boiler-house of approximately 24 ft. × 50 ft., allowing for the inclusion of a third similar boiler unit, as is provided for in the existing boiler-house.

The boilers in question are each 10 ft. diameter × 12 ft. long between the tube plates, and they each contain 38 tubes of 6-in. internal diameter. The method of developing surface combustion in these tubes and the refractory packing is similar to that employed on the smaller tubes, there being slight modifications which have been developed as the result of a series of experiments with this particular gas made on a single-tube tank for the purpose of discovering the best arrangement.

The two feed heaters supplied with these boilers have each a capacity equal to the total of two boiler units, so that one feed heater can be put out of action without interrupting the load. The same remark applies to the two power-driven exhausters. One of these is driven by a 440-volt continuous-current motor, and the other by a steam turbine.

Particular interest attaches to this plant, as it represents the first occasion upon which Bonecourt boilers have been used as a link in the system of generating power from coal by means of ammonia-recovery gas producers. The tendency of modern engineering to conserve the valuable by-products contained in coal instead of wasting these in coal-fired boilers has been emphasized so frequently at meetings of learned societies that it is very fortunate that an opportunity has been found of demonstrating the important part which it is hoped the Bonecourt system of steam-raising must inevitably play in power undertakings of the future.

It is not often that such an expensive form of fuel as the illuminating gas of London can be advantageously employed for steam generation, but there is one instance of a Bonecourt boiler at work in a large factory in London, the boiler being fired with illuminating gas from the town main and supplying steam to a steam hammer. The boiler is 8 ft. long and 3 ft. 6 in. in diameter, and is provided with five tubes, each of 6-in. bore. The boiler is capable of evaporating about 2,000 lb. of water per hour, but normally it is found sufficient to work it at about half its possible output.

The justification for the use of so expensive a form of fuel in this instance is to be found in the convenience and adaptability of the plant. The readiness with which steam can be raised when wanted for the hammer, and the immediate manner in which the making of steam responds to the turning on and off of the gas, are found to offer a great convenience in work of such an intermittent nature.

A novel type of construction has been adopted for this boiler. The tubes, instead of being of uniform bore throughout, contract sharply at the entrance end, the first 6 in. of the tubes being only of such bore as is required for the supply of the gaseous mixture. By adopting this plan of construction, the use of fireclay plugs for closing the entrance ends of the tubes is dispensed with, and the first part of the tube which conveys the gaseous mixture to the fireclay packing is kept cool by the water in the boiler. This special construction of the tube is shown in Fig. 3.

The use of a granular refractory packing for the purpose of increasing the rate of heat transmission is not limited to boilers which are fed with combustible gas. The same device may be employed for the purpose of increasing heat transmission in so-called waste-heat boilers, where the heating medium consists of products of combustion from a furnace or gas engine. There is no question of surface combustion in the tubes of the boiler in this case, the granular packing serving merely to increase the heat transmission through the walls of the tube by radiating heat from the hot granules and also by

causing the hot gases to impinge repeatedly on the tube walls.

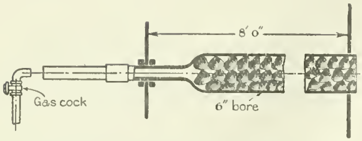

Fig. 3.

A sectional view of a Bonecourt waste-heat boiler that has been supplied for utilizing the exhaust gases of a gas engine is shown in Fig. 4. The boiler consists of a shell 5 ft. 6 in. in diameter and 3 ft. long, provided with 35 tubes of 3-in. bore, giving a total heating surface of 109·9 sq. ft. During a test the load on the engine varied between 70 and 150 h.p., but the boiler is of sufficient capacity to work in conjunction with an engine of 300 h.p., as is proved by the fact that this boiler, with 18 of the tubes purposely plugged with stoppers, thus reducing the heating surface to 54 sq. ft., evaporated 250 lb. of water from and at 212° F. per hour, this amounting to 4·7 lb. of water per sq. ft. of

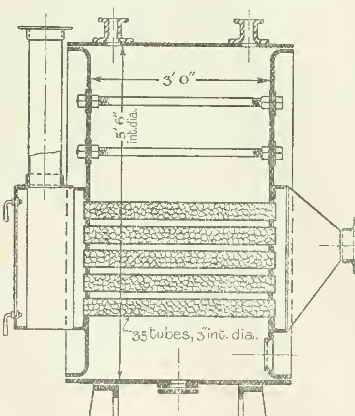

Fig. 4.

heating surface per hour. It was found that 17 tubes afforded sufficient outlet for the gases without putting undue back-pressure on the engine, and we may therefore conclude that in boilers of this class it is sufficient to provide 0·37 sq. ft. of heating surface for each indicated horse-power of the engine. This is a very low ratio of heating surface to work done, and enables waste-heat boiler plant of very compact dimensions to be constructed.

Under the above stated conditions of working, with the heating surface of the boiler reduced by rather more than one-half, the inlet temperature of the gases was 610° C. and the outlet temperature 150° C., with a steam pressure in the boiler of 60 lb. per sq. in.

Liquid Fuel.

So far the author has dealt with the Bonecourt boiler fired with gaseous fuel or with hot waste gases; and he now proposes to describe recent developments which have resulted in the successful adaptation of the Bonecourt system for firing with liquid fuel.

At first sight there might appear to be something anomalous in the idea of hot surfaces accelerating the combustion of liquid fuel, but when it is considered that the combustion of liquid fuel is only a special case of gaseous combustion, and that when liquid fuel is burned what really burns is the combustible vapour given off by the heated liquid, the possibility of utilizing hot surfaces for accelerating the combustion of liquid fuel appears more feasible.

After many unsuccessful attempts the author has succeeded in devising means for utilizing liquid fuel in Bonecourt boilers. Those who have tried to secure complete combustion of liquid fuel in contact with or in close proximity to water-cooled surfaces will readily appreciate the fact that many difficulties presented themselves in translating the Bonecourt system from a gas proposition into a liquid-fuel proposition. Those difficulties have now been overcome, and a way found whereby results may be obtained with liquid fuel which are quite comparable with the results obtained with gas.

The experiments were carried out in the works of Messrs. Bonecourt Surface Combustion, Ltd., in London, and culminated in the construction of a liquid-fuel-fired boiler, which is now running the works. This boiler is 5 ft. in diameter and 12 ft. long, and is furnished with five boiler tubes each 9 in. in bore. The boiler tubes are packed with refractory material arranged on the staggered plan. The liquid fuel is supplied to the boiler tubes from an overhead tank under a pressure due to a head of about 12 ft. The air required for the combustion is supplied from a fan at a pressure of from 5 to 30 in. water gauge, the oil and air supplies to the boiler tubes being so arranged that the oil is sprayed by the air. A simple arrangement is employed in the entrance of each boiler tube which provides a gasification chamber for the spray of liquid fuel. The arrangement is shown in Fig. 5 and comprises a fireclay sleeve which serves the purpose of conserving heat within the chamber, and a perforated septum which forms the further wall of the chamber.

The process of lighting consists in swinging back the spray device, inserting some lighted oily waste, and turning on the oil and air. In a few seconds the chamber is red-hot, as is seen by inspection through the sight tube, which is fixed in such manner as to give a good view of the middle of the chamber. The chamber being red-hot, it is only necessary to turn on the oil and air to the required extent, the appearance of the glow serving as the indication for determining the correct proportioning of oil and air. All the tubes can be lighted by one man in three minutes, and steam at 110 lb. per sq. in. is obtained in 50 minutes starting with everything cold.

The purpose of the chamber, as has been mentioned, is to gasify, or at all events partially gasify, the liquid fuel. The gasification is brought about by the heat of the chamber and the partial combustion of the liquid fuel, this partial combustion serving to maintain the chamber at the required temperature. The chamber is far too

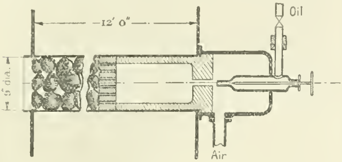

FIG. 5.

small to enable complete combustion of the fuel to take place, and this point has been proved by analysing a sample of the gases drawn through a water-cooled tube of very small bore from a point situated in the fireclay packing immediately after the perforated septum. The gas sample drawn off analysed :—

	Per cent
Carbon-dioxide	11·4
Oxygen	0·3
Carbon-monoxide	11·2
Saturated hydrocarbons equivalent to	10·0 Methane
Nitrogen	67·1
	100·0

It will be seen that the sample contains a considerable amount of combustible gas, and that at the particular point at which the sample was taken the gaseous medium consisted mainly of combustible gas with the almost complete exclusion of oxygen. A sample of the gaseous medium drawn from a neighbouring point showed a large excess of oxygen, and as analysis of the products of combustion leaving the end of the boiler tube showed the combustion to be complete, it is clear that if samples of the gasified material were taken from a sufficient number of points in the cross-section immediately after leaving the gasification chamber, it would be found that the gaseous medium leaving the gasification chamber consists in the aggregate of combustible gas together with sufficient air to complete its combustion subsequently in contact with the incandescent refractory material in the boiler tube, a certain amount of products of complete combustion being also present.

The following are the results of a test carried out on the oil-fired boiler referred to, which is installed in the London works of the Bonecourt Company, and is in regular operation, supplying the works with power.

Steam gauge pressure (per sq. in.) ...	110 lb.
Temperature of oil	80° F. (27° C.)
Air pressure	37 in. (water gauge)
Pressure in smoke-box	3 in. „
Temperature of combustion products leaving boiler tubes and entering feed-water heater	608° F. (320° C.)
Temperature of combustion products leaving feed-water heater	275° F. (135° C.)
Temperature of cold feed	43° F. (6° C.)
Temperature of feed from feed-water heater to boiler	119° F. (48° C.)
Duration of test	3 hours
Total water evaporated	7,625 lb.
Water evaporated per hour	2,542 lb.
Water evaporated per hour from and at 212° F.	3,085 lb.
Total tube surface (five tubes 9-in. bore, 12 ft. long)	141 sq. in.
Total heating surface of boiler ...	123·7 sq. ft.
Steam raised per sq. ft. of heating surface per hour from and at 212° F.	25 lb.
Total oil burned	545 lb.
Oil burned per hour	181·7 lb.
Water evaporated from and at 212° F. per lb. of oil	17·0 lb.
Net calorific value of oil (per lb.) ...	17,800 B.Th.U.'s

$$\text{Efficiency} = \frac{7625 \times 1175{\cdot}9 \times 100}{545 \times 17800} = 92{\cdot}5 \text{ per cent}$$

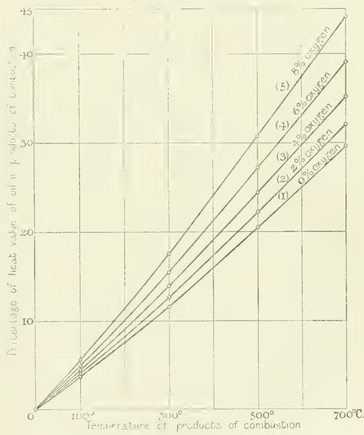

FIG. 6.—Admiralty Fuel Oil. Curves showing percentage of heat value of the oil contained in the products of combustion at various temperatures and with various oxygen contents. Measured from 0° C.

A continuous sample of the combustion products was taken during the test, and was found to analyse :—

	Per cent
Carbon-dioxide	12·8
Oxygen	3·4
Carbon-monoxide	0·0
Nitrogen	83·8
	100·0

The oil burned in this boiler is the ordinary class of fuel oil as supplied for the firing of boilers on torpedo-boats and for steam raising and furnace firing generally. Experiments have been made with several kinds of oil, and no difficulty has been experienced in burning any kind of oil that was tried. If the oil contains much bitumen and is so viscous as not to flow readily, it is found advantageous to warm the oil, but for any ordinary kind of fuel oil perfectly satisfactory results have been obtained when the oil has been supplied cold to the boiler.

The points which characterize this boiler may be enumerated as follows:—

1. Complete combustion of the oil, no products of partial combustion being found in the flue gases.
2. The air required for complete combustion of the oil is only slightly in excess of the theoretical requirement.
3. Entire absence of smoke when once the boiler has been started up, and practically no smoke while starting.
4. The oil is supplied to the boiler cold and at a very low pressure, the air supplied for the combustion being sufficient to effect the necessary spraying of the oil.

water on entering and leaving the feed-water heater it will be seen that the 92·5 per cent of the heat utilized is divided into 83·7 per cent transmitted through the boiler tubes and 8·8 per cent transmitted through the tubes of the feed-water heater. We thus obtain as the distribution of heat utilized and lost:—

			Per cent
Heat transmitted through boiler tubes	83·7 %	Heat utilized	92·5
Heat transmitted through tubes of feed-water heater	8·8 %		
Heat lost in products of combustion at 135° C. ...			5·2
Balance, being radiation loss			2·3
Total heat available in oil burned			100·0

As a check on the above estimate of radiation loss, a careful measurement of actual radiation loss from the boiler shell was made by observing the fall in steam pressure when the boiler was laid off with an initial steam pressure of 99 lb. per sq. in., the figure obtained being 2·1 per cent, which agrees very closely with the above.

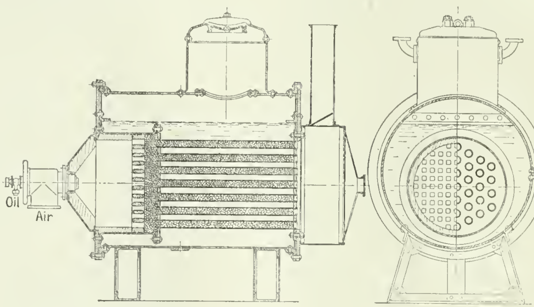

Fig. 7.

5. The combustion products are cooled down to a point below which further cooling would scarcely be practicable or economical.
6. An evaporation of 25 lb. of water per sq. ft. of heating surface per hour.
7. The effective transmission to the water in the boiler of 92·5 per cent of the net heat available in the oil burned, even when evaporating at the above stated high rate.
8. Exact and immediate regulation of steam production.

In order that we may be in a position to examine critically the utilization of heat in this boiler system, the author gives in Fig. 6 some curves showing the heat content of the combustion products at different temperatures and with different percentages of oxygen, such heat contents being measured from a datum line of 0° C. and expressed as a percentage of the net calorific value of the fuel. From inspection of this curve it will be seen that the products of combustion of liquid fuel at 135° C. and containing 3·4 per cent of oxygen contain as sensible heat 5·2 per cent of the heat originally available in the oil burned, while on comparing the temperatures of the feed-

It is well to note in passing that this radiation loss amounts to 226 B.Th.U.'s per hour per sq. ft. of exterior surface of lagging for a mean boiler pressure of 90 lb. per sq. in., the thickness of the lagging being 2 in.

Although this system of oil firing has only recently been evolved, another boiler has been built and supplied to a customer. The products of combustion after leaving the boiler tubes are returned through a tube in the steam space, in which are disposed steam coils for the purpose of superheating, the products of combustion after leaving the superheater passing to a feed-water heater consisting of the usual drum traversed by packed tubes. The boiler has been in operation for a month or two and is giving entire satisfaction.

This method of oil firing has been taken up in Germany by the Berlin Anhaltische Maschinenbau Aktiengesellschaft, who are developing the subject of surface combustion in collaboration with the Bonecourt Company. With the object of testing an alternative mode of construction they have built a boiler following the same

general principles, but in which one combustion chamber supplies a number of small boiler tubes. This boiler is shown in Fig. 7. It comprises a boiler shell provided with packed tubes of 3-in. bore and a feed-water heater furnished with similar tubes. The author is informed that good results have also been obtained from this boiler, and it would appear that the plan of construction involved may afford a useful alternative.

Solid Fuel.

The author has discussed in this paper the use of gaseous fuel with the Bonecourt boiler, and has also shown how such boilers may be fired with liquid fuel. There remains therefore only to apply the system if possible to solid fuel —the largest field of all. This field of investigation has already been attacked, and although a Bonecourt boiler fired direct with solid fuel is not yet a *fait accompli*, the attempts which have so far been made in this direction afford hope of a very useful result being obtained at no distant date. The experiments which have already been carried out have produced remarkable results: in a small apparatus fired with solid fuel, evaporating 334 lb. of water per hour from and at 212° F., complete combustion of the fuel has been obtained, although the amount of air supplied for the combustion was practically no more than is required by theory, as is shown by the following analysis of the combustion products:—

Carbon dioxide	19·1 per cent
Oxygen	1·4 "
Carbon monoxide	0·0 "
Nitrogen	79·5 "
	100·0 "

The evaporation amounted to 17·8 lb. of water from and at 212° F. per square foot of heating surface per hour. Such a result is remarkable from the point of view of both a combustion phenomenon and the evaporation performance. This result was communicated by the Bonecourt Company to their German allies, the Berlin Anhaltische Maschinenbau Aktiengesellschaft, who expressed themselves sufficiently impressed with the results to undertake immediately the further development. They have constructed a coal-fired Bonecourt boiler and are about to put it under test. This first construction is naturally of a tentative nature, but it is hoped that it will pave the way for a considerable enlargement of the field of surface combustion as applied to steam generation.

Discussion.

Mr. Jockel. Mr. L. M. Jockel: Papers dealing with boiler work are very welcome as it seems that at the present time further improvements in the efficiency of steam plant are more necessary in the boiler house than in the engine-room, especially when one considers that in many up-to-date power stations something like 50 to 70 per cent of the works costs is accounted for in the boiler house. On page 724 the author states that a draught of about 15 in. (water gauge) is required, and that this can be produced either by induction or by forcing. If the latter method is adopted it appears that two fans will be necessary, one for the gas and one for the air; in all probability, however, the induced-draught arrangement will prove in practice the more satisfactory and efficient of the two methods. To produce this pressure difference an appreciable amount of power will be required—possibly some 3 to 4 per cent of the power developed by the boiler—and this fact must be considered when comparing boiler efficiencies. In land practice with water-tube boilers working on induced draught the power required for driving the fan seldom exceeds about 1 per cent of the boiler power. In connection with the driving of the fan the lay-out shown on page 727 represents a duplicate fan plant arranged for both electrical and steam-turbine drive. The latter method might prove very economical, as the heat in the exhaust steam could be utilized for heating the feed water previous to its entering the gas-fired heater or economizer. On the other hand this arrangement might not prove so reliable, as during heavy loads the draught would be largely dependent on the boiler pressure. At such times in a power station one naturally wishes to speed up the auxiliary plant in order to get over any difficulty such as low steam pressure as quickly as possible. The evaporative power of the boiler would appear to be some 3 to 4 times greater than in the case of an ordinary water-tube boiler, and it would be interesting to know whether priming does not occur when working at such high rates— particularly in view of the fact that nowadays such excellent results of boiler tests are published from time to time. As high superheats are now of great importance it would be of interest if the author could give details of suitable superheaters, as no mention seems to have been made of their application to this type of boiler. The compactness of the boiler should be a valuable feature in many cases, the lay-out shown on page 727 illustrating this point. An ordinary water-tube boiler appears to require about 18 sq. ft. of floor space per 1,000 lb. of water evaporated per hour, whereas a Bonecourt boiler would only require say 14 or 15 sq. ft. of space for the same duty. On page 728 the author mentions in connection with an oil-fired boiler that steam at 110 lb. pressure can be raised from cold water in 50 minutes. In view of expansion troubles this would hardly seem to be good practice with a shell-type boiler, particularly with a multitubular design having a large ratio of diameter to length and flat stayed surfaces. From practical experience with multitubular boilers of the shell type I have always found that there is a certain amount of "dead" water present unless some efficient circulating device is utilized; but perhaps the author gets over this difficulty by placing the fire tubes very low down in the boiler. The maintenance of boilers is an important factor, and it would be interesting if the author in his reply could give some figures in regard to that item, as I understand that some Bonecourt boilers have now been working under practical conditions for over a year. In view of the high evaporative rating, it would seem that scaling would be frequently required unless the feed water is remarkably pure, while unless the gas is carefully cleaned the fire tubes and granules will tend to get clogged. The latter difficulty might possibly be overcome by periodically refluxing the tubes.

Mr. Selvey. Mr. W. M. Selvey: The Bonecourt system will be of great use to the community when it has found its right

Mr. Selvey. sphere. A suggestion rather than a positive statement is made on page 727 in the paragraph which states that Bonecourt boilers have been used as a link in the system of generating power from coal by means of ammonia-recovery producers. I think that this is not borne out by the circumstances quoted. All that I see in it is a boiler installation for supplying the Mond type of producers with the large quantity of steam which on the one hand is so necessary if a large yield of ammonia is to be obtained, and on the other hand is so detrimental to the heat efficiency. I have no wish here to open up this old controversy; those interested can refer to the discussion on Mr. Humphrey's paper before the Institution of Mechanical Engineers,* but I feel compelled to point out that if Mr. McCourt wishes us seriously to consider this boiler as a link in the chain for obtaining power from coal via a producer, a steam boiler, and a steam turbine, rather than by producer plant and a gas engine, then I must certainly dissent from the balance sheet for the efficiency of his boiler. It is the old question of the producer efficiency being taken on the "gross" or "higher value" of the gas, and the gas-engine efficiency on the "net" or "lower value." I have come to the conclusion that with a Mond type of plant, with a boiler of the highest efficiency that I have personally tested, and with steam supplied to the producer from a mixed-pressure turbine, the amount of coal burnt in the producer-boiler system is 1·43 times that of the same boiler with a modern chain grate. Now this coal-fired boiler had an efficiency of over 85 per cent reckoned on the "higher value," and on the "lower value" it would have had an efficiency of over 88 per cent, so that accepting the author's figure of 95 per cent for this boiler, and deducting 2 per cent for "extra" fan power, we are only 5 per cent better off and the ratio is only reduced from 1·43 to 1·36. Now this chain-grate boiler which I have in mind would burn even the poorest class of coal, whereas the producer to go with this boiler would require a coal not only carefully selected but containing a high percentage of nitrogen. I look for the solution of the problem therefore rather on the lines of the combined coke-oven-waste-heat power station in which this boiler may legitimately find a field. In such cases land is generally cheap and the size of each unit is small. The present boiler is a return to the fire-tube type, which has generally been limited to an evaporation of about 15,000 lb. per hour, whereas our modern large power stations are now being fitted with Babcock and Stirling boilers which can easily evaporate 40,000 lb. of water per hour—indeed, in the United States a number of boilers of the Stirling type have evaporated 100,000 lb. per hour. The Bonecourt boiler, to give an efficiency of 95 per cent, has an economizer that reduces the temperature of the outlet gases almost to the condensation point of the water vapour carried by them. The effect of any such condensation will be known to those who have occasionally run economizers with feed water below 90° F.; a solution of sulphuric acid is produced which plays havoc with the metal-work. I expect that the author has already heard of this. Corrosion would also occur in the suction fan if it were placed in the outlet gases; but I think that this could be remedied by placing the fan between the boiler and the economizer. It may be news to some members that economizers of the pipe type have already given outlet temperatures lower than those mentioned in the paper, and with a fan power of only 2 in. (water gauge) instead of the 15 in. to 30 in. quoted. The extra power required for this draught as compared with the usual type of fan has not been debited against the 95 per cent efficiency claimed. The outlet temperature from the boiler itself is quite a normal figure for a water-tube boiler, and there is no particular item from the combustion to the temperature of the outlet gases that could not be produced by other means at present available. The fan power is quite a considerable item. The power required for 1,000 cub. ft. of air at a pressure of 20 in. (water gauge) is 3·04 h.p. Assuming reasonable efficiencies, I find that the power required for the fan for an electrical drive is equivalent to 2·9 per cent of the steam generated—Professor Bone in one of his papers allows 4 per cent. If the steam is provided by a high-pressure turbine and its exhaust is used for feed-water heating, the consumption will not be better than double this figure, which means practically 6 per cent of the total steam. This is nearly as much as the feed water can take up under ordinary conditions, having already the steam from the feed pump, and is enough to prevent the final temperature of the gases from approaching 200° F. The electrical drive is of course dependent on electrical power always being available before the boilers are started up. There are several other points which might be put forward, such as the arrangements for meeting rapidly varying loads and the adjustment of the ratio of the gas and air, on which the author could give us welcome information. I should like to close my remarks with a note of appreciation. The author has produced a boiler situation similar to that in connection with gas engines, in which the small unit is as efficient as the large. He has put forward an exceedingly clever flash boiler on a much larger scale than hitherto, and has provided a means of prolonging the life of many small private plants which are using steam as an alternative to electric power supply from a large company.

* H. A. Humphrey. Power-gas and large gas-engines for central stations. *Institution of Mechanical Engineers, Proceedings*, p. 41, 1901.

Mr. Christianson. Mr. W. A. Christianson: The author refers to the possibility of using boilers of the water-tube type worked on the Bonecourt gas combustion system, but he has shown no actual designs. The Bonecourt system of combustion is excellent, and had it been arranged so that it could be adapted to boilers of existing types more progress might have been made. So far, development appears to be confined to boilers of the fire-tube type, and the largest size made up to the present is only of 11,000 lb. per hour evaporative capacity. There is therefore not sufficient inducement for power users to discard their existing boilers for Bonecourt boilers. No reference has been made to the use of blast-furnace gas on the Bonecourt system, and blast-furnace gas is undoubtedly a most important field of gas firing. It seems to me that it would be necessary to clean the gas first, as otherwise the boiler tubes and granules would become badly choked after a short time. Cleaning of blast-furnace gas has made considerable progress in Germany, but not so much in this country, and therefore I think that the Bonecourt system will not be adopted in this sphere. The boilers described by the author supply saturated steam only. For present-

Mr. Christianson. day power installations it is essential to have superheated steam, and it would seem to be a matter of some difficulty to arrange for this with a Bonecourt boiler, as the exit flue-gas temperature at the back of the boiler portion is too low for superheating purposes. The high efficiency claimed appears to be to a great extent due to the feed-water section. Reference to one of the author's tests shows the exit temperature from the boiler section to be 608° F., while of the total efficiency of 92·5 per cent, 83·7 per cent is due to the boiler and 8·8 per cent to the heater. The figures corresponding to the boiler are by no means exceptional, and I am of opinion that equally good results are being obtained from coke-oven gas-fired boilers of ordinary make where similar care is taken in the working of the boiler as has been done in these Bonecourt boiler tests. Blast-furnace gas-fired boilers are notoriously inefficient, but the same cannot be said of coke-oven gas-fired boilers. Although figures are not generally published, I think that with reasonable care efficiencies of 85 per cent would be obtained. The high efficiency of the Bonecourt system is further due to the surface combustion with its resulting minimum amount of excess air, and the impinging effect caused by the granules in the tubes. The surface combustion can be imitated in a simple fashion by properly arranged chequered brickwork in the furnace chamber of any water-tube boiler, and as in boilers of this class the impinging principle on the tubes is already fairly well carried out, I am hopeful that such a combination would be equal in practical efficiency to the Bonecourt system—especially so in a boiler of the Stirling type where the back section of tubes is practically an economizer section. The impinging or retardation principle in fire tubes has already been appreciated, as evidenced by occasional attempts to fit retarders to marine boiler tubes. These have generally had to be discarded owing to choking. Coal-fired boilers have generally lower efficiencies than coke-oven gas-fired boilers, and this should be borne in mind when considering the high efficiency claimed for the Bonecourt system. For the present I think that the Bonecourt boiler is suitable only for small plants. Incidental advantages of the system are that the nozzle control allows each burner and tube to be worked at its maximum efficiency throughout a wide range of power, while in case of low water it is possible to shut off the top burners and so prevent damage. A disadvantage is that the boiler is not readily adapted for changing over to coal firing, which is sometimes necessary. With the multiplicity of burners used on gas-fired boilers, there is the possibility that the mixture in each may vary, resulting in a lower efficiency; but this difficulty is satisfactorily overcome in the oil-fired boiler shown in Fig. 7, which has a preliminary mixing chamber. On previous occasions the diaphragm principle of firing gas on the Bonecourt system has been put forward, and I thought that this might have been adapted so that it could be used on existing types of water-tube boilers. Perhaps the author will tell us why no such development has taken place. About twelve months ago I inspected the boiler at Skinningrove and was informed that it was giving very satisfactory results. With regard to the author's statement that the evaporation is proportional to the square root of the difference of pressure between the opposite ends of the boiler tube, I have found that a similar law applies to an ordinary chain-grate coal fire. Perhaps the author will be able to enlighten us further on several of the points referred to—more especially in regard to adapting his principle to existing makes of boilers for large powers, and in regard to comparisons with existing methods.

Mr. McCourt. Mr. C. D. McCourt (*in reply*): The following points have been touched upon in the discussion, and I propose to consider them in the order in which they arose, namely:—(1) Power consumption for fan driving; (2) the possibility of priming due to the high rates of evaporation obtained; (3) the provision of superheaters; (4) the possibility of straining a Bonecourt boiler by too rapid starting from cold; (5) the cost of maintenance of the boilers; (6) the necessity for removing scale deposited on the tubes; (7) the possibility of the boiler tubes becoming clogged up internally by dust deposited from gaseous fuel; (8) the cost of generating steam by means of ammonia-recovery producer gas; (9) corrosion of the feed-water heater and fan due to condensation; (10) the suitability of the system for meeting rapidly varying loads; (11) the employment of blast-furnace gas.

Turning first to the question of power consumption for fan driving, it should be remembered that the figures which have been recorded up to the present have been measurements upon fans not expressly constructed to give good efficiency for the duty required. In the case of large installations of Bonecourt boilers it would be possible to use standard fans having efficiencies ranging between 70 and 80 per cent for a considerable variation in load. The results of carefully made tests on exhausters of large capacity, constructed by the De Laval Company of Sweden, show that for large boiler installations the percentage of power necessary for driving the exhausters may be reduced far below the figures mentioned in the discussion; in fact, taking the fan tested, over a considerable variation in load the fan power would be below 2 per cent of the boiler output. With regard to the power required for the fan, it should be recollected that centrifugal fans possess the useful property of giving when driven at a constant speed almost constant suction for very great variations in load.

Careful measurements have been made of the wetness of the steam produced from Bonecourt boilers evaporating at high rates, and in every case the steam has been found to be technically dry. The excellence of the circulation induced by the steep evaporation gradient along the tubes is probably partly responsible for the absence of priming, but a more important factor in this connection is that the boiler in question is a fire-tube boiler and not a water-tube boiler. If a water-tube boiler were to evaporate at the high rates obtaining in a Bonecourt boiler, the steam formed in the tubes might be expected to shoot water into the steam spaces and cause serious priming. Water tubes are known to act spasmodically in the generation of steam, and can be observed acting much in the manner of pop-guns if a suitable model be constructed and operated.

Superheaters can be readily provided in Bonecourt boilers, the boiler tubes being chosen on the short side so as to obtain the necessary temperature of the combustion products, the superheater being located between the boiler and the feed-water heater, and the feed-water heater having to do a little more work by reason of the increased temperature of the entering gases. If a high degree of superheat be required, the boiler can be designed of a short

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length and furnished with an equal number of combustion tubes and return tubes, the superheater being located at the end of the boiler shell and therefore being subject to a surrounding gaseous medium at a temperature of 600 to 900° C.

It has been suggested that if boilers of high steaming power such as the Bonecourt boiler are started quickly, straining will take place owing to unequal heating of the shell. This has not been found to occur, and immunity in this respect is attributable to the vigour of the circulation produced by the steep evaporation gradient along the tubes. The vigorous circulation prevents the formation of "dead" water at the bottom of the boiler, and hence every part of the shell increases in temperature at a nearly uniform rate however quickly steam may be raised starting from cold.

With regard to cost of maintenance of the boilers, the absence of heated joints and the restriction of the heat transmission area to the tube surfaces must make for a low cost. Bonecourt boilers have not as yet been sufficiently long in use commercially to afford data on this head, but they have at all events been sufficiently long in use to show that during two years' operation no necessity for repairs of any kind has been encountered either in the straining of the shell or the burning or impoverishment of the boiler tubes or tube joints.

No trouble has yet arisen with regard to scale formation. The scale formed on the tubes is shed off as soon as it reaches a thickness of about a millimetre. On opening the Bonecourt boiler at Skinningrove after it had been running for some months, no scale thicker than a millimetre was found on the tubes, but in the bottom of the boiler shell was found an accumulation of detached scale, which had evidently been dropped from the tubes after attaining a certain thickness.

Experiments have been made with gases heavily laden with dust, and it is found that very little dust settles in the boiler tubes. The speed of the gases passing through the tubes effectually prevents serious deposition of dust, any dust tending to collect being at once moved on by the violence of the blast.

With regard to the comparison between the relative advantages of Bonecourt boilers and gas engines for the development of power from ammonia-recovery producer gas, it is thought that a discussion of this subject, involving as it does a full consideration of a great diversity of points, cannot advantageously be entered upon here. It will be evident, however, that the simplicity and low first cost of large turbine sets of say 10,000 to 12,000 kw. offer compensating advantages to set against the lower fuel consumption of gas engines limited to sets of about 2,000 kw.

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It has been suggested that the gases in passing through the feed-water heater of a Bonecourt boiler are cooled down to the point at which condensation may take place, and that if this occurs it will be found to cause serious corrosion. This can be obviated by causing part of the hot feed water to circulate back again to the inlet of the feed-water heater, thus preventing such undue cooling of the flue gases as would produce condensation and consequent corrosion.

To meet variations in load, any number of tubes can at a moment's notice be turned off, and when required again can as quickly be lighted up. To do this it is only necessary to manipulate a damper and the necessary valves. By this means any desired output of steam from 1 per cent to 100 per cent of the maximum output can be obtained at any time. A more elastic control of steam generation can scarcely be conceived, the response of the boiler to alterations in the supply of gas being immediate.

Coming finally to the firing of Bonecourt boilers with blast-furnace gas, two large boilers each evaporating 15,000 lb. of water per hour are about to be constructed by a large firm in Belgium for their power station. Preliminary experiments have been carried out at their works, the gas employed possessing a calorific value of 105 B.Th.U.'s per cubic foot, and yielding an evaporation of 20·5 lb. of water from and at 212° F. per square foot of heating surface per hour. The flue gases analysed :—

Carbon dioxide	16·4 per cent
Oxygen	2·6 ,,
Carbon monoxide	0·0 ,,
Nitrogen	81·0 ,,
	100·0

This composition shows that the combustion is complete even when the amount of excess air employed is almost negligible.

THE CONSTRUCTION OF A WIRELESS STATION.

By C. G. Roach, Associate Member.

(*Paper read before the* Western Local Section *16th March*, 1914.)

ABSTRACT.

About four years ago it was decided to spend a large sum on improvements in the ship-to-shore wireless service, and on completion of the scheme there will be 12 stations having the following ratings, viz.:—

	kw.		kw.
Valentia	10	Guernsey	$1\frac{1}{2}$
Malin Head	5	Bolt Head	3
Liverpool	2	Land's End	5
Caister	$1\frac{1}{2}$	Fishguard	3
North Foreland ...	$2\frac{1}{2}$	Crookhaven	3
Niton	$1\frac{1}{2}$	Cullercoats	2

The stations acquired from the Marconi Company at Rosslare and the Lizard have been abandoned, and those at Bolt Head and Guernsey will be maintained for use in emergencies only.

The Land's End station was opened for traffic on the 1st December last. It is situated close to the main road from Penzance to St. Just, and within a mile of the latter town. The station stands 500 ft. above sea-level, and the ground has a gradual fall to the sea, thus affording the best possible conditions for ship-to-shore signalling.

The original scheme was to obtain the electrical energy for working the station from the Cornwall Power Company's 10,000-volt mains, but it was subsequently found necessary to install prime-movers and to generate the electrical energy required.

There are two lattice steel masts each 205 ft. 6 in. in height and fitted with three sets of four stays. Originally it was intended that they should stand on porcelain feet, but owing to the high cost of such massive insulators, which would have had to be specially made, it was decided to substitute reinforced concrete feet. The diameter of each block is 36 in. The blocks stand 18 in. high and are 36 in. in diameter, and there are three for each mast. The stay anchorages are formed of T-shaped blocks of concrete reinforced with $\frac{1}{2}$-in. iron rods. Each block is estimated to weigh 18 tons. Running through the concrete at an angle of 45 degrees is a $1\frac{1}{2}$-in. iron rod, 9 ft. in length, threaded through a 6-ft. length of channel iron $4\frac{1}{2}$ in. × 2 in. × $\frac{1}{2}$ in. at the lower end and fitted with a 6-in. ring at the upper end to take the stay attachments. The stays are made of $2\frac{1}{2}$-in. steel rope. The topgallant stays have three block porcelain insulators, and the topmast and mainmast stays two each. The stays terminate at the ground anchors with a short length of crane chain and a special clamp which admits of a fine adjustment by nuts, and of a coarse adjustment by taking up a half-link or a number of links in the chain.

The masts, which were designed by the Engineer-in-Chief to the Post Office, are of triangular section, and will maintain their stability when subjected to a wind having a velocity of 80 miles per hour. The main members are composed of bent steel plate of uniform thickness, and are connected end to end by suitable fish-plates. The braces are of 2 in. × 2 in. × $\frac{1}{4}$ in. angle iron and are fitted to the vertical members by two rivets at each end. Their lengths are for the mainmast 5 ft. $11\frac{1}{2}$ in., topmast 4 ft. $7\frac{3}{4}$ in., topgallant mast 4 ft. $0\frac{5}{8}$ in. Owing to the extreme length of the sections, 70 ft. 10 in. main, 65 ft. $7\frac{1}{4}$ in. topmast, and 66 ft. $5\frac{1}{4}$ in. topgallant-mast, they were sent down in half-sections, each half-section being nested together for convenience of transport and erection. The moving-derrick method was employed for erecting the first mast, but in the case of the second mast this method was abandoned and treble and quadruple blocks taking a 4-in. manila rope were used instead. The untelescoping was by no means an easy job owing to the extreme lengths to be handled and the small overlap between the sections, but it was carried through in due course and successfully completed. The masts will doubtless do all that is expected of them, but the cost of carriage and erection will probably prevent the perpetuation of that particular design.

The mast erected at Fishguard consists of three sections, the dimensions being as follows:—

Mainmast 65 ft. × $13\frac{1}{2}$ in. square, tapering to $11\frac{1}{2}$ in.
Topmast 58 ft. × $11\frac{1}{2}$ in. square, tapering to $9\frac{1}{4}$ in.
Topgallant-mast 51 ft. × $9\frac{1}{4}$ in. square, tapering to $6\frac{1}{2}$ in.

This type of mast is the one usually adopted for coast stations, the timber used being pitch or yellow pine.

The Marconi Company's latest mast is of tubular design built up in sections, each section being about 10 ft. in length. The half-sections are pressed out of sheet steel and flanges are formed at the sides and ends, which are drilled to take the connecting bolts. To facilitate erection a wood spar is fitted inside the tube and gradually raised until the required height is attained. The spar serves to hold the tackle necessary to carry a balcony on which the men work and to raise the half-sections as the work proceeds; finally it supports the antenna above the steel structure. The advantages attending the use of this type of mast are the moderate cost of transport and the ease of erection; against which must be set the increased resistance offered to wind pressure as compared with the lattice-work mast.

The International Convention on Wireless Telegraph Traffic decided that each coast station must be able to work with either a 600-metre or a 300-metre wave. To provide for this at Land's End two separate antenna are used. The 600-metre antenna consists of an inverted triangle, the base being 200 ft. and each of the sides 160 ft. in length. Both the base and the sides are formed of cages of six wires separated by light wooden spreaders with the ends brought together on stout copper rings. The first cages were made of 7/19 S.W.G. hard-drawn copper wire but in future silicon bronze is to be substituted, copper having failed to stand the severe strain.

This aerial is suspended by $1\frac{1}{2}$-in. flexible steel cables, running over suitable sheaves attached to the top of the masts, and thence to two 5-ton winches which are anchored permanently for raising and lowering the cages. The 300-metre aerial is much lighter and can be easily handled with a set of double-purchase blocks. It consists of two wires, each 141 ft. in length, separated by two spreaders. The halyard is a 2-in. hemp rope rigged on the mast standing at the south-west corner of the site. Vulcanized rubber strop insulators are interposed between the aerials and their halyards. The earth system is of the capacity type and consists of 20 cast-iron plates No. 18 gauge, each plate measuring 6 ft. × 3 ft. They are arranged on either side of the building in two arcs of 80 ft. radius measured from the centre of the high-tension room. The plates were buried as nearly vertical as possible without having recourse to blasting, and their upper edges are bolted together. To the centre of each plate a copper wire, weighing 100 lb. per mile, is attached and led over a short stake to a rolled-steel frame erected on a platform on the roof of the building, and insulated therefrom by 4 Buller's third-rail insulators. Each of the 20 wires from the earth-plate is clamped to the outside of the frame, and from the inside six wires are led to a Bradfield insulator fixed at the centre of the platform. On either side similar insulators are placed for terminating the two aerials.

The wave-changing switches are operated by means of a lever switch mounted on the side of the receiving cabinet and acting through flexible steel wires run over rollers. There are six 0·014-mfd. and one 0·016-mfd. condensers.

The motor-alternator carries a 10-in. disc discharger at its free end. The whole of the high-tension apparatus is enclosed by a wire screen provided with two entrance doors, each of which is fitted with a safety switch, so that any person entering the danger zone automatically disconnects the circuit. The conductors used for leads are strips of copper $1\frac{1}{4}$ in. × 3/32 in. separated by ebonite strip $3\frac{1}{2}$ in. × $\frac{1}{8}$ in. The copper strip is shaped to ensure the minimum length, and all joints are riveted and soldered. The leads from the Bradfield insulators are 20-ampere cord flexible. The disc discharger has 12 sparking studs, corresponding to the 12 poles of the alternator.

The leads from the earth discharger to the receiving cabinet are stout copper wires run through the walls on partition insulators. The receiving cabinet is of special design and fulfils two functions: it shuts out the noise of the running machines, and by means of an earthed screen of wire netting built into its walls it shields the receiving apparatus from inductive disturbance. Two detectors are used, the Marconi magnetic and a crystal set. In order that low-resistance telephones may be used with each detector, a step-down transformer is interposed between the crystal and the telephone.

In carrying out tests of the efficiency of the station it was noticed that stronger signals reached Crookhaven than were received at Fishguard. Good signals were exchanged with Bolt Head, but Niton can only be reached occasionally. The range westward has been proved up to 1,200 miles, and very considerable distances south have been reached. The efficiency to the west is so marked that power has to be reduced in order to avoid interference with Crookhaven. These results go to prove that there is considerable screening to the east, but in all other directions the range is good. In this connection it is interesting to note that the Land's End station was the first to answer the s.s. *City of Philadelphia's* distress call when she recently went ashore at Rame Head, near Plymouth.

The power plant includes two oil-engines, each capable of developing 10 b.h.p. at a speed of 700 revs. per minute. The continuous-current generators are direct-coupled, have shunt-wound field magnets, and are designed for an output of 5 kw. at 100–140 volts with a speed not exceeding 1,000 revs. per min. The motor-alternator set consists of a continuous-current 100–140-volt compound-wound motor coupled to a single-phase alternator which has a stationary field and a revolving armature designed to give a single-phase current at 300 volts and 200 periods per second, with a total output of 5 kw. The normal current is 18 amperes. The armature and field magnet windings of both the alternator and the motor are protected from surges by guard lamps.

The transformer is of the closed-magnetic-circuit type with independent windings, and the secondary is wound in sections, the whole being insulated and cooled by immersion in oil. It raises the voltage from 300 to 8,700, and the test showed an overall efficiency of 93·7 per cent. The high-tension terminals are mounted on large porcelain insulators and are provided with a safety gap and discharging horns. The gap is adjustable so that the maximum voltage shall not exceed 57,000. Two switchboards are provided; the one in the engine-room controls the continuous-current generator, the charge and discharge of the battery, and the supply to the motor-generator, auxiliary motors, and lighting circuits; the other switchboard is installed in the high-tension room and is designed for controlling the motor-alternator from a remote-control fixed in the operating cabinet.

The starting switch and resistance is of the Bray Markham and Reiss type, and is operated by two tumbler switches, one fixed on the power board and the other in the silence cabinet, so that the operator has full control without leaving his seat. A second field-regulating resistance in series with that on the power board is fitted in the silence cabinet to enable the operator to reduce the amount of power if required.

The equipment of the switchboard in the engine-room includes 3 watt-hour meters; No. 1 records the total units generated, No. 2 the energy used for lighting, and No. 3 that expended on signalling. The transmitting key is joined direct in the primary circuit of the transformer and is provided with a second pair of contacts through which the receiving circuit is made when the key is at rest, and broken when the key is depressed. The battery consists of 52 cells with a maximum discharge of 378 ampere-hours at the 9-hour rate.

DISCUSSION ON

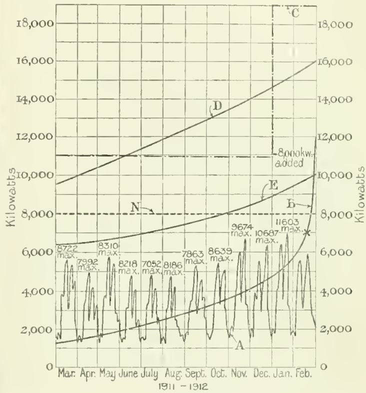
"A TWO-RATE TARIFF SYSTEM WITHOUT TIME-OPERATED CONTROL."*

YORKSHIRE LOCAL SECTION, 11TH MARCH, 1914.

r. urnand.

Mr. W. E. BURNAND : The object aimed at by the author is obviously to encourage the use for long periods of the small proportion of lamps that the consumer would use if the rate were low enough, and at the same time to obtain the full price during the ordinary dark hours when the load is in the neighbourhood of the maximum. Although it would be rather difficult to explain to the consumer the system in which a low rate per unit is charged for a small consumption and a high rate for a large consumption, I think that there should undoubtedly be a limited field for the device described by the author, and that it will have to some extent the effect of obtaining some revenue that might otherwise be lost. There appear, however, to be two rather serious disadvantages of the author's system, the first being that in common with the maximum-demand and similar systems which give an increased rate on the consumer's periodical demands, it tends to induce economy on the consumer's part, probably several hundred times per year when this is no advantage whatever to the supply authority. The second point is that in common with the telephone and other systems in which the high charge is based upon the lighting consumption, the proposed tariff is not on a very secure foundation, as, owing to the low efficiency of the method of converting electrical energy into light, very great reductions are possible in the future in the consumption of energy for lighting, whilst the same does not apply to anything like the same extent to other electrical apparatus. I think it is reasonable to expect that in a few years' time lighting will cease to be the predominating factor in the cost of electricity supply, and that heating and other uses will take the place now held by the lighting load. Any system that ignores such conditions is bound to give trouble sooner or later as the load factor and the distribution of the load vary from time to time. What is required is a system that automatically adjusts the amount of revenue according to the cost of giving the supply. On page 43 the author states that "the mere granting of a low flat rate for power by many authorities to-day is an admission that the diversity factor is large enough to allow the coincidence of double peaks to be ignored." My opinion is that so far from this coincidence of double peaks being of no importance, it is to-day really the most important factor and is likely to continue to be so for a very long period with the present demand for unprofitable units, that is to say the demand which lasts for so few hours per year that the outlay on the plant required to deal with it is altogether out of proportion to the revenue received.

Apart from this double-peak coincidence, I think that the simplest and most generally satisfactory tariff is one which comprises a simple fixed charge dependent on the character of the service required plus a low rate per unit. The rateable-value system of charging which is so much in vogue at the present time—justified perhaps by its value as a business getter—approximates to this ideal, since, although the fixed charge is based upon the rateable value of the house, it is recognized that as other uses become more prominent relatively to the lighting load this rateable value will have to be altered. The charge is therefore really based on both the rent of the house and the service demanded, and it will eventually vary more with the character of the service than with the rent or rates. Going back to the question of coincident peaks, the accompanying diagram will, I think, show that the Mr. Burnand.



importance of this is very much greater than anybody would expect who has not looked somewhat closely into the matter. Curve A, for which I am indebted to Mr. S. E. Fedden, shows the average distribution of the lighting and power load at Sheffield throughout the day for each month of the year 1911. It does not show the maximum variation, but the highest peak observed during each month is marked in figures at the top of each average peak shown in Curve A. By extending this average peak to the maximum and reducing the width so that the curve still encloses the same area, and then adding together all parts of equal height, we get Curve B, which shows the total time per annum during which the load has reached any given value. It should be noted that all these values are taken from ammeter readings, so that these curves represent kilovolt-amperes and not watts. Curve C represents the amount of generating plant installed. As, however, the capital outlay is not confined to the generating plant, the greater proportion of it being due to mains and the distribution system, Curve C hardly corresponds to the capital outlay, which would really more nearly

* Paper by Mr. H. H. Perry (see pp. 42 and 150).

Mr. Burnand.

approximate to Curve D. Thus the area enclosed below Curve D shows the total rating of the plant available for the supply, and Curve B the energy actually generated. The difference between the two areas indicates what a large increase in output is possible by improving the load factor and with only a small addition to the capital expenditure. The chief point that I want to bring out, however, is the expensive nature of Curve B above the point marked X (which represents only about 50 hours' use of the plant per annum) due almost entirely to coincident peaks. Supposing that it were possible to control these peaks so that we should be quite certain that with the existing connected load the demand on the supply system would not exceed that represented by the point X, everybody would agree, I suppose, that the plant capacity indicated by Curve E would be sufficient to deal with this load. That shows that the whole of the plant represented by the difference between Curves B and D is required in order to cope with the demand above the point X on Curve B. The difference between Curves D and E is about 5,000 kw., which at £40 per kilowatt (including the generating plant, buildings, mains, and distribution system) represents £200,000, whilst the actual revenue from the current supplied for the period when the demand exceeds the value X is only something like 200,000 units, which at say 2½d. per unit only bring in £2,000. This very unprofitable return could not, of course, be covered by any reasonable increase in the tariff. The best way to deal with this over normal peak load, if feasible, is to get rid of it altogether by obtaining control over the peak load and letting the consumers know when this load is on, so that all unimportant load may be switched off and the load above the point X thereby reduced. By thus keeping down unprofitable plant expenditure obviously a lower charge could be made for the current supplied, with a corresponding increase in the consumption and a better load factor, both of which tend to decrease the cost still further. To prevent repetition of matter already published I would refer any one interested to the discussion on the papers by Mr. A. H. Seabrook* and Mr. W. W. Lackie† and also to an article which I contributed to the *Electrical World*.‡ The only system giving control of the character proposed over the peak and at present actually in use is that developed by Messrs. Duddell, Dykes, and Handcock.* I wish to disclaim, however, any suggestion that this system is in any way the result of suggestions made by myself.

* A. H. SEABROOK. Residence tariffs. *Journal I.E.E.*, vol. 48, p. 376, 1912.

† W. W. LACKIE. Tariffs for electrical energy, with particular reference to domestic tariffs. *Journal I.E.E.*, vol. 49, p. 147, 1912.

‡ W. E. BURNAND. Low rates and the development of the central-station service. *Electrical World*, vol. 59, p. 261, 1912; see also *Electrician*, vol. 68, p. 919, 1911–12.

Mr. Perry.

Mr. H. H. PERRY (*in reply*): Mr. Burnand considers that the basis of the system proposed is partially unsound for two reasons, but I think that the system has at least no greater weakness than there is in those systems hitherto in use; and it must be taken as a maxim that no system can be perfect. If the consumer can be induced to be careful with his supply, it may be taken for granted that he will be a very regular user and unlikely to cause extravagant peaks. I quite agree with Mr. Burnand's view that lighting will cease in a few years' time to be the predominating factor owing to the rapid demand for energy for heating, cooking, and perhaps power for domestic uses. He takes exception to the possibility of double peaks being beneficial in the long run, but if heating and cooking make the headway expected, the peaks due to that load will not be merely double, or two per day, but quadruple; and in this way one must look for a large increase in the load factor, and so fill up many of the gaps shown in his very interesting curves obtained at Sheffield.

The rateable-value system of charging, together with a low rate per unit, is undoubtedly popular, but at its best it is an approximation, and nobody can argue that every consumer is being treated on his merits. It may encourage the very worst consumer whose consumption is low on a high maximum demand, and whose annual bill is altogether too low in proportion. It would seem to be a system which needs a great amount of initial personal adjustment as between the consumer and the supply authority, particularly where different classes of consumers have to be catered for, and it is doubtful whether it readily attracts new business from the small consumer.

It is somewhat difficult to criticize the curves shown and to offer any suggestions as to a suitable tariff to fill up the gap between curves B and C, but it would seem likely that should the lighting load become of secondary importance, the improvement in the load factor must of necessity have become an accomplished fact. At such a stage the price will be very low and the task of selecting a suitable tariff will be made easy—the reversion to a pure flat rate may be the outcome for all-day users.

* W. DUDDELL, A. H. DYKES, and H. W. HANDCOCK. The control of meters, public lamps and other apparatus from the central station. *Journal I.E.E.*, vol. 50, p. 240, 1913.

DISCUSSION ON

"THE SIGNALLING OF A RAPID-TRANSIT RAILWAY."*

NEWCASTLE LOCAL SECTION, 8TH APRIL, 1914.

Mr. Fleet. Mr. E. F. FLEET: This paper contains information that has never been published before in tabular form, although the subject has for many years been considered almost daily by signal engineers. As the paper presupposes certain conditions, and is written to substantiate the occurrence of those conditions, it cannot be criticized. The conditions, however, are those of suburban traffic where all the trains are of practically the same length and run at the same speed. I have been connected with automatic signalling for a considerable time and these problems arose in an acute form about 8 years ago in connection with the automatic signalling on the North-Eastern Railway from Alne to Thirsk. We considered that the overlap should be determined by the traffic conditions. Thus, whilst the lengths considered in the paper are expressed in feet, owing to the different conditions the length of the sections in our case was something like 1,300 yards between signals and the overlap was 400 yards. It was also necessary to consider various speeds from 15 miles per hour up to 60 miles per hour, but the principle was the same as that described in this paper, although the conditions being different we had naturally to deal with the problem somewhat differently. For instance, the author does not refer to a warning signal; he deals with absolute length signalling. That, I am afraid, would not be applicable to the conditions on trunk lines, where the trains may be either a few feet or 400 yards long—or even half a mile long—and we had to do something to meet these conditions. The author mentioned that the overlap was 300 ft., and referred to special overlaps for through trains, but I should like to know what the limit is for through traffic. He also mentioned speed control from the track. I have had considerable experience in the maintenance of track control in connection with the cab-signalling system of Mr. Raven and Mr. Pigg,† and I have had to maintain permanent-way ramps for some years. There is of course a great deal of variation owing to the wear and tear of sleepers and owing to various other considerations, so that if speed control is added I am quite sure that it would be impracticable and that a lot of delicate adjustment and tests would be required before it could come into very general use. There is no mention of gradients in the paper because, I take it, of the conditions which the paper sets out to explain. I may say that the system where the signals stand normally in the clear position does not appeal to me: I prefer the old system where the signals stand at danger until the section is cleared. It is a small point to some people, but I think that it is a question of principle and that it should be followed except perhaps where the existing method of block working is entirely dispensed with.

Mr. Prescott. Mr. C. W. PRESCOTT: With reference to the author's remarks on the accumulative effect of delays at stations, I should like to know if any form of bell or other signal has been used to warn the station staff when a train has exceeded the maximum allowable station stop. This arrangement ought to be fairly simple, and would perhaps check the delays before the margin left between the operating conditions and the theoretical limit of the signalling was exceeded. I was rather surprised that the sighting distance shown on the diagrams is less than the overlap, because I always look upon the overlap as dependent on the emergency braking, and the sighting distance as dependent on the service braking. I notice that the maximum speed taken for the calculations in the paper is 25 miles per hour; this might seem rather low when considered in relation to steam practice and also to express electric trains. It is a rather interesting point that the possible headway is absolutely dependent on the maximum speed with the type of signalling under discussion—that is, with train stops. The distance between two stations is divided up into two overlaps, one sighting distance, and a certain length of time during which the train is running at maximum speed, this length of time being equal to the station stop. There is therefore for a definite spacing of stations an absolutely definite maximum speed which will give unchecked running. If the trains are capable of exceeding this maximum speed they are not being used to the best advantage and energy is being wasted. If they are incapable of attaining this maximum speed, passengers are not being carried as fast as possible. It is a simple matter to plot this relationship as a curve; 25 miles per hour is a suitable maximum where the stations are spaced close together—something of the order of 0·4 mile apart. It is quite probable that in the future when an electrification scheme with stations very close together in the central area and comparatively far apart on outlying lines is being considered, it will be made impossible for the drivers to exceed a certain low maximum speed in the central area, this speed being raised in the outlying area: for instance, for a given set of conditions the maximum speed suitable for a station spacing of 0·4 mile is 30 miles per hour, whereas that for 0·8 mile spacing is 50 miles per hour. I am much interested in what the author says about speed control: it certainly seems as if the ideal system had not yet been developed.

Mr. Peters. Mr. R. PETERS: What impresses me most in this paper is the graphic method used by the author in arriving at his results. This method may be a commonplace to signal engineers, but to me it appears very ingenious. In connection with the improvement of train timing, the system advocated involves an addition to the number of signals, and consequently an increased risk of drivers mistaking them. It seems to me that cab-signalling will partly solve this problem, probably by means of what may be termed a "wireless" device. It should not be impossible to combine with such a contrivance a form of speed control.

Mr. Williams. Mr. O. R. WILLIAMS: I take it that this paper deals with services where electric power is employed, and conse-

* Paper by Mr. H. G. Brown (see p. 545).

† J. PIGG. Automatic cab-signalling on locomotives. *Journal I.E.E.*, vol. 40, p. 62, 1908.

Mr. Williams quently that, whatever speed is assumed, all the trains would have the same maximum speed, thus justifying the assumptions made. There is one point that I should like to mention in connection with Fig. 3; the resultant delay due to a 10-second stop is shown as 19·45 seconds, which period after the home signal has been passed is sufficient to bring the train into the station section. The time taken for trains to decelerate from, and to accelerate to, a speed of 25 miles per hour is 19·45 seconds, but of course the trains would not enter the platform at such a speed. At some point previous to that the driver of the first train would start to decelerate, and similarly the driver of the second train; therefore I think that the estimate of 19·45 seconds is not strictly accurate when both trains are decelerating in order to stop at the station, and this would seem to have some effect on the resultant delay. Another point is that when working at double the minimum time interval a delay to the first train will not cause a delay to the second train unless such delay is sufficiently long to cause the home signal to go to "danger," which is equivalent to working at something below the minimum time. This again would not delay the train unless train No. 2 was stopped for such a time as to cause it to come within the minimum time again; consequently bunching should only take place with a few trains unless the original delay is considerable.

Mr. Brown. Mr. H. G. Brown (*in reply*): The intention of the paper was to explain the principles, and the data given have been taken from railways of the London Underground type. The principles explained can be applied to any railway, being applicable to a line having different data from those given.

Mr. Fleet referred to the necessity of using distant signals. I am strongly of the opinion that, particularly on rapid-transit lines, in practically every instance a repeater or distant signal should be installed to work in conjunction with each stop signal. It is always found in practice that a decrease in the train interval as well as a saving in power is obtained by the addition of repeating signals.

In reference to the normal-clear position for automatic signals, an overwhelming majority of such signals are installed on the normal-clear principle, and when the normal-danger system is preferred for automatic signals the preference is probably due to the precedent established by the normal position of the manually-controlled interlocked signal. The only virtue of a signal is to impart information to the driver of an approaching train. A manually-controlled signal should be normally in the danger position because it is the interpreter of the will of the signalman who is capable of, and must use, selective discretion. The signal is not supposed to indicate the condition of the portion of the line that it governs, but to give access to that portion of the line when, and only when, the signalman considers it advisable that such access should be given, and it is the will of the signalman that no movement should be made except on his own initiative. An automatic signal should stand normally in the clear position. It interprets the condition of the portion of the line that it governs, and it is not controlled by human agency, being an automatic mechanism and necessarily without discretion. If the section of the line is clear, the signal should indicate that fact; and vice versa. The main arguments against the normal-danger system are as follows: It is illogical, as the signal does not correctly interpret the condition of its section at all times. It costs more to install and maintain, and there is a greater liability of failure, as it requires more instruments and material than its equivalent on the normal-clear system. Any normal-clear system can be changed to a normal-danger system by the addition of apparatus. In the normal-danger system, the circuits must be arranged so that an approaching train sets the signal to the clear position when its section is unoccupied. A normal-danger system therefore becomes a normal-clear system when the traffic increases beyond a certain point, because the signal stands in the clear position an increasing percentage of the time that the section is clear in direct proportion to the increase in the frequency of the trains.

Mr. Prescott asked if it would not be advisable to arrange for a bell to ring when the time allotted for the station stop had expired. As far as I know, this has not been done, and the idea would be worth the consideration of traffic officials.

The sighting distance has been taken as the deceleration distance, which would naturally be the minimum. On railways of the London Underground type it is considered advisable to allow a distance of 600 ft. wherever possible, but the deceleration distance has been given in the paper, as anything beyond this figure is a question of the personal equation of the driver.

Attention has been called to the maximum speed of 25 miles per hour used in the illustrations. While the maximum speed is important, it is not as important as the rate of deceleration and acceleration when the stations are near together. This will be evident when it is remembered that a large proportion of the entire time during which the train is moving is occupied by decelerations and accelerations.

Cab signalling is a very difficult question. Only a few systems now in use are satisfactory, and these are successful because the principles of design are sound, and also because they do not attempt too much. For some time yet cab signalling should be considered as an auxiliary to the existing systems of signalling, and not as a complete system in itself.

COMPARATIVE TESTS ON SINGLE-PHASE ALTERNATING-CURRENT COMMUTATOR MOTORS.

By E. A. Richards, B.Sc.Eng., Graduate, and D. Dunham, B.Sc.Eng., Student.

(*Paper read before the* Students' Section *7th May*, 1913.)

The following paper consists mainly of a record of experiments carried out in the laboratories of the City and Guilds Engineering College (London) on alternating-current commutator motors, the object of these tests being to compare the performances of the same machine when running as an Atkinson, Fynn, Latour-Winter-Eichberg, or synchronous motor. The last mentioned is of course a constant-speed machine, and the Atkinson and Fynn motors nearly so, whilst the Latour-Winter-Eichberg motor has a series characteristic.

As in the case of continuous-current motors these machines may be made to have either a series or shunt characteristic. Traction motors are naturally of the series type, and on account of the large demand for this type of motor much work has been done in perfecting them, with the result that they are now established as commercial machines.

Although Mr. Fynn and others have written papers dealing with commercial forms of the alternating-current shunt commutator motor, these motors have only recently come into extended practical use. They are suitable for many classes of work, such as the driving of machines, lifts, etc., where a larger starting torque is required than can be obtained with a single-phase induction motor, and they are particularly valuable in cases where speed regulation is required. For these reasons they should have a wide field of usefulness, in spite of the difficulties which have to be overcome in their design.

With the exception of tests in which the authors assisted Mr. F. Creedy on a motor of his own design, the tests here described were all carried out on a Fynn motor built by the Alioth Company of Basle, and rated at 140 volts 57 amperes at 1,430 r.p.m. The rotor of this machine is an ordinary continuous-current series-wound armature with a commutator of 117 segments. There are also four slip-rings connected to equidistant points in the winding. The commutator carries four sets of brushes displaced 90° electrically from one another. The stator is built up of laminations and carries three distinct windings disposed in slots :—

(*a*) A 4-pole partially distributed winding termed in this paper the main or transformer winding, S_1;

(*b*) A similar but smaller winding displaced half a pole pitch from (*a*) and termed the auxiliary or starting winding, S_2;

(*c*) A compensating winding, S_3, of a few turns only, placed in the same slots as the main winding.

The ends of these windings are brought out to separate terminals, enabling the motor to be connected in various ways, in order to carry out the tests described below.

The motor was first tested as an Atkinson motor, connected as shown in Fig. 1 (*a*). For simplicity the motor has been considered throughout as a two-pole machine, in which case the four sets of brushes would be equally spaced round the commutator. The Atkinson motor is not self-starting, and so it is necessary to connect it as a repulsion motor as shown in Fig. 1 (*b*) to start up, and switch over to the Atkinson connections when running.

At starting, then, the current in the main winding S_1 induces a current in the short-circuit axis A A by transformer action. This secondary current in conjunction with the field due to the winding S_2 produces a torque, the direction of which depends on the direction of connection of S_2. When the motor is running a back E.M.F. is induced along the A A axis due to the cutting of the lines of the field produced by S_2 by the rotor conductors. This E.M.F. opposes the secondary transformer current and so determines the speed of the motor for any given torque. The repulsion motor has, of course, nearly a series characteristic. The rotor conductors also cut the field due to S_1, and an E.M.F. is thereby produced at the brushes B B. If these brushes are short-circuited when the motor has attained full speed, a current will flow in the B B axis and produce a field along that axis. The winding S_2 can now be cut out and the motor will continue to run, the motor field being produced by the current in the rotor along the B B axis. In all cases of a field being produced by the rotor, it is important to bear in mind that the axis of the flux coincides with the axis of the brushes, since the magnetic reluctance is practically uniform all round the gap.

The vector diagram of the Atkinson motor is shown in Fig. 1 (*c*). Starting with the applied voltage V, we have the transformer flux N_1 practically in quadrature with it, and the transformer E.M.F., E_T lagging 90° behind the flux. Due to the rotation of the rotor conductors in this flux we have E_B (the E.M.F. in the B B axis) in phase with N_1, and causing the current I_B to flow in the B axis. Owing to the high self-induction of the armature along this axis, I_B lags by a large angle behind E_B, and the motor flux N_2 set up by it will be almost in quadrature with E_B. Due to rotation in N_2 we have the back E.M.F., E_A, opposing E_T. The resultant of E_T and E_A is E_R, which is the vectorial sum of I R, the drop of pressure due to resistance, and E_S, the inductive drop in the A A axis. The armature current I_A is in phase with I R. The resultant of the current I_A and the stator current I_S must be the magnetizing current I_0 which is necessary to produce the flux N_1 along the A A axis; and from the position of the vector I_A the power factor of the stator is necessarily low. It will be seen from the figure that there is a large phase displacement between the armature current I_A and the motor flux N_2, thus necessitating a large armature current for a small torque and limiting the output of the motor.

The conditions may be somewhat improved by adding self-induction along the B B axis by means of an external choking coil. The effect of this is to make I_B lag still more behind E_B, consequently displacing N_2 still farther

and decreasing the angle between the motor flux N_2 and the armature current I_A. It will be noticed also that by displacing N_2 still farther back E_A is also moved, and this brings I_A still more into phase with N_2. By adding inductance in this manner I_B is necessarily reduced, and consequently the field N_2 is weakened and the speed increased. This method can be used to a limited extent for speed control.

Fig. 2 shows the curves of performance of this motor both with and without added self-induction in the B B axis. It will be observed that the output is small, the maximum being about 3 b.h.p. without, and 4 b.h.p. with, additional self-induction. The efficiency in the first case only reaches 51 per cent, and the power factor 0·5. These are increased to 58 per cent and 0·62 respectively by adding self-induction. It will be noticed that the current in the A A axis reaches about 100 amperes in each case, and that it is increasing very rapidly. It is obvious that and flux should be in phase at full load although the power factor is thereby somewhat reduced. This point is further discussed in connection with the curves of performance of the motor. The compensating E.M.F. is in phase with E_T, and can therefore be induced directly by transformer action from the main stator winding. A winding, S_3, consisting of a few turns is placed in the same slots as the main winding, and is connected across the brushes B B in place of the short-circuit used in the Atkinson connection.

The connections of this motor are shown in Fig. 3. At starting the windings S_1 and S_2 are connected in series by means of the switch H, the B B brushes being open-circuited. The machine starts up as a repulsion motor as previously explained. When up to speed the resistance R in the B B circuit is cut out, and at the same time the switch H is moved over the stops, cutting out the winding S_2 in three steps. To reverse the direction of

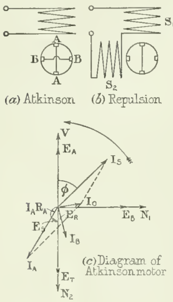


FIG. 1.

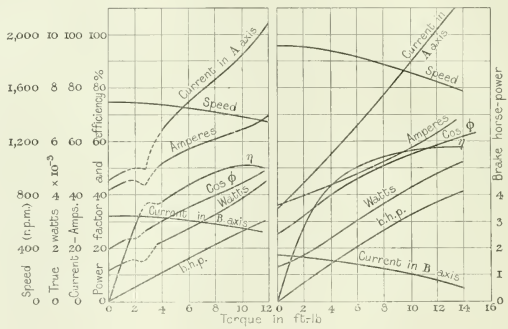


FIG. 2.

(1) Atkinson Motor. (2) Atkinson Motor, with extra self-induction in B B axis.

in this form the motor cannot be considered as a commercial machine. The performance of the motor is, however, greatly improved by the addition of the compensating device invented by Mr. Fynn, and described by him in a paper read before the Institution in 1906.*

The method adopted is to add a small E.M.F., E_C, in the B B axis in quadrature with E_B. Referring to Fig. 3, the result is to shift E_B to E_B'. The consequent displacement of N_2 and E_A causes N_2 to lag in phase behind I_A, and since the stator current I_S must always be determined by the resultant of I_A and I_O, it is now brought nearly into phase with the applied voltage. By suitably choosing the amount of compensation the power factor may be increased to unity at any particular load. This result is only possible, however, if there is a phase displacement between the flux N_2 and the current I_A; and as this current practically limits the output of the motor it is very desirable that this current

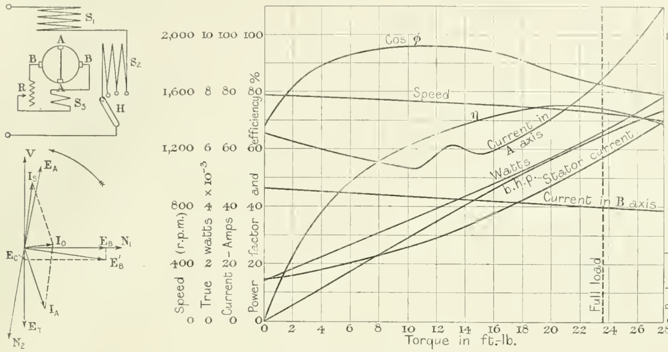
* V. FYNN. A new single-phase commutator motor. *Journal I E.E.*, vol. 36, p. 324, 1906.

rotation, the connections to S_2, and also to the compensating winding S_3, are reversed.

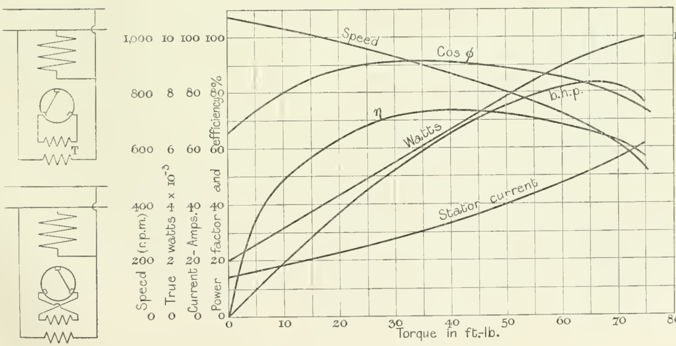
Fig. 4 gives the result of a constant-voltage test on the motor thus connected, and it illustrates the striking improvement effected by the use of the compensating winding; for the same armature current the torque is doubled. The full-load efficiency has risen to 75 per cent, and the output of the motor is correspondingly increased. At no-load the stator current leads on the voltage, but as the load increases the phase displacement becomes less, the power factor being nearly unity at about half full load and then decreasing, although not very rapidly. As explained above, the power factor at any load depends entirely on the magnitude of the compensating E.M.F. and not on the dispersion coefficient as in the ordinary induction motor. Complete compensation can, however, only be attained at the expense of increased copper loss in the rotor. It will be observed that the current in the B B axis and therefore the motor flux N_2 are nearly

constant, being proportional to the speed. The armature current I_A depends on the load and the angle between I_A and N_2, and since this phase angle decreases at first more rapidly than the load increases, I_A falls to a minimum value, after which it increases with the load. After full load is reached this increase becomes very rapid, since the of his design, built by Messrs. Parkinson, of Leeds, and he has kindly given permission to publish the results.

This motor is shown diagrammatically in Fig. 5. The stator is wound with six salient poles, and the rotor is an ordinary continuous-current armature with three sets of brushes on the commutator. The brush arrangement for



FIGS. 3 AND 4.—Fynn Motor.



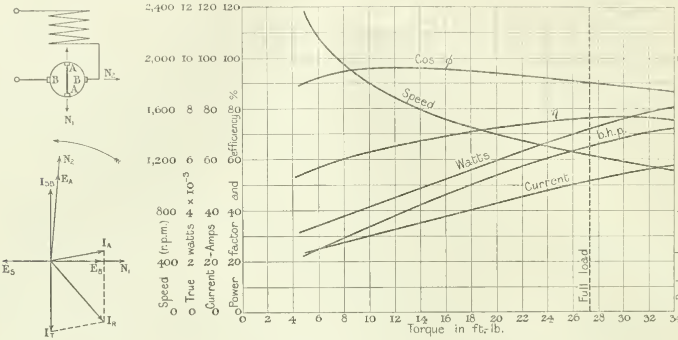
FIGS. 5 AND 6.—Creedy Motor.

current is again out of phase with the flux, and consequently the efficiency begins to fall off. At no-load the speed is slightly above synchronism, falling uniformly about 10 per cent over the whole range of load.

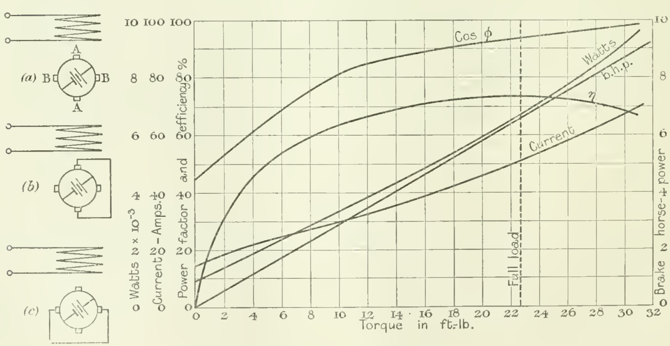
In addition to the tests carried out on the Fynn motor, the authors had the privilege of assisting Mr. Creedy in carrying out some tests on a new commutator motor a similar two-pole motor is shown in the figure. The compensation on this motor is provided by an external transformer T, the primary of which is connected in parallel with the stator across the mains. With the secondary of this transformer disconnected we have an ordinary repulsion motor. With the transformer connected the compensating E.M.F. is introduced into what

corresponds to the B B axis of the Atkinson motor, and raises the power factor to unity at some particular load. On account of the magnetizing current of the transformer, the power factor of the whole motor is somewhat lower than unity, reaching about 0·91 at full load. The motor having been designed especially for lift work has a 65 amperes. This current can be somewhat reduced by varying the amount of compensation, but the power factor suffers in consequence. In fact, by adjustment of the compensation the motor may be given any characteristic intermediate between shunt and series.

For the sake of comparison the original Fynn motor was



FIGS. 7 AND 8.—Latour-Winter-Eichberg Motor.



FIGS. 9 AND 10.—Synchronous Motor.

very high starting torque—starting being effected by switching the motor straight on to the mains, thus simplifying the external connections.

The performance curves of this motor are shown in Fig. 6. The efficiency at full load is about 74 per cent and the power factor 0·91. The starting torque at 220 volts—the working voltage of the motor—is about 75 lb.-ft., $2\frac{1}{2}$ times full-load torque, with a current of next tested as a Latour-Winter-Eichberg motor. The connections and vector diagram are shown in Fig. 7. The latter is taken from a paper read by Messrs. Page and Scott before the Students' Section,* in which this motor is fully dealt with. The authors therefore do not

* G. W. P. PAGE and G. J. SCOTT. Single-phase commutator motors, especially the Latour-Winter-Eichberg type. *Journal I.E.E.*, vol. 47, p. 779, 1911.

propose to deal here with this type in detail. The performance curves are given in Fig. 8. This motor having a series characteristic the speed decreases rapidly as the load increases. At about synchronous speed the motor has its maximum power factor of 0·97. The efficiency at full load reaches 76 per cent at a power factor of 0·90.

It has been previously mentioned that the motor is provided with slip-rings connected to equidistant points in the armature. Brushes were fitted to two rings connected to diametrically opposite points, and the machine was run as a synchronous motor, continuous current being led into the rotor by means of these rings to form the field-magnet system. Connections were first made as shown in Fig. 9 (*a*). Starting was effected as a repulsion motor, and when synchronous speed was reached the continuous current was switched on to the rotor and the auxiliary winding cut out through a resistance. It was found to be impossible to load the motor to any extent without pulling it out of step owing to the high reactance of the stator. The A A axis was therefore short-circuited as shown in Fig. 9 (*b*) to reduce the stator impedance. In this way satisfactory running was obtained up to well above full-load output. In order to prevent any ill-effects from the short-circuiting of the continuous-current excitation as the slip-ring connections passed under the brushes, a choking coil was connected in series with the continuous-current source of supply.

It was hoped that by running the machine as a synchronous motor a greater efficiency would be obtained, as the iron losses are a minimum at synchronous speed ; but owing to the necessity for short-circuiting the A A axis, and the consequent heavy I^2R losses in the rotor, no improvement was effected in this direction. The experiment has some interest, however, as an example of a self-starting synchronous motor. The power factor can of course be varied at will by altering the amount of the continuous-current excitation. The motor was also tried with the B B axis short-circuited, the idea being that this would act as a compensating winding and prevent the phase-swinging of the flux. This was unsatisfactory as the motor pulled out of step in the same way as when there was no short-circuit. Excessive sparking prevented the running of the motor with both axes short-circuited.

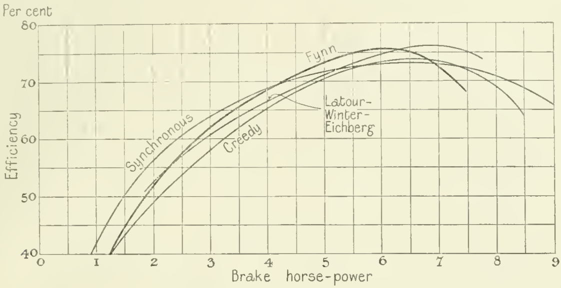


FIG. 11.—Efficiencies.

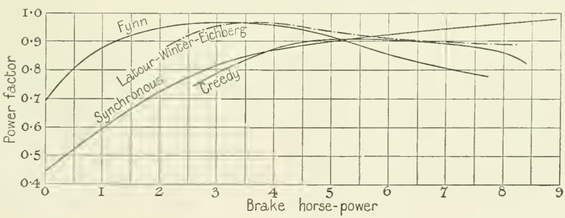


FIG. 12.—Power Factors.

The performance curves of the synchronous motor with the A A axis short-circuited are shown in Fig. 10. To obtain the necessary torque at heavy loads the motor was over-excited and so a leading power factor was obtained, viz. 0·45 at no load, rising to 0·93 at full load and nearly

unity at 40 per cent overload. The efficiency reached 73 per cent at full load.

In Fig. 11 the efficiencies of the Fynn, Latour-Winter-Eichberg, synchronous, and Creedy motors are shown together, plotted with the brake horse-power as abscissæ. It will be seen that the efficiencies in each case are nearly the same, varying from 73 per cent to 75 per cent at full load, which figures compare fairly favourably with those of single-phase induction motors of the same horse-power. Efficiencies of about 85 per cent are obtained with Fynn and Creedy motors of 30 to 50 h.p.

The power factors are compared in the same way in Fig. 12 and range from 0·85 to 0·92 at full load, the figures for the Fynn and Latour-Winter-Eichberg motors being somewhat higher at about half load. The synchronous motor, as explained before, was taking a leading current, as was also undoubtedly the case with the Fynn and Latour-Winter-Eichberg motors at light loads. Of course the synchronous motor could be adjusted to give nearly unity power factor at all loads, the curve given referring only to the case where the excitation is kept constant throughout.

The starting performances of the Fynn, Latour-Winter-Eichberg, and Creedy motors are shown in Fig. 13, the Fynn motor starting as a plain repulsion motor. The Creedy motor being a 220-volt machine, the equivalent currents at a pressure of 140 volts are plotted in this case. The starting torque is plotted with the values of the current as abscissæ. It will be seen that with the Latour-Winter-Eichberg connection a considerably higher torque is obtained for the same current than with the repulsion-motor connections. This is merely a question of the relative strengths of the two flux components in the repulsion motor, and, of course, leakage is less in the Latour-Winter-Eichberg machine as the field is produced directly by the rotor. The latter gives twice full-load torque with about $1\frac{1}{2}$ times full-load current. The Creedy motor gives about $2\frac{1}{2}$ times full-load torque with twice full-load current.

Experiments were carried out to determine the proportion of the various losses in the Fynn motor when connected according to the different methods described. The losses occurring in the motor may be classified as follows:—(*a*) Resistance losses in stator and rotor; (*b*) brush contact and resistance losses; (*c*) friction and windage losses; (*d*) eddy current and hysteresis losses, including under the former title the losses due to currents circulating in the coils short-circuited under the brushes.

The losses under heading (*a*) merely resolve themselves into accurate determinations of the resistances of the various circuits and the currents flowing in them, and therefore require no special consideration.

(*b*) The brush losses were experimentally determined in the following manner:—The Fynn machine was driven by means of a belt from an adjustable-speed continuous-current motor. A pair of brushes on the same spindle were used for the test, one brush-holder being in contact with the spindle and the other insulated from it. A measured continuous current was led in at one brush, along the commutator segments, and out at the other brush, and the drop of potential in the two brushes in series was measured with a voltmeter. In this way a series of readings was taken at various speeds for a number of constant values of the current. As the segments pass under the brushes the resistance varies, so that the current as measured on an oscillograph would appear like a continuous current with a high-frequency alternating current superposed on it, and the voltage would follow the same variations. Moving-coil instruments read the average values of the current and voltage, and therefore the product differs from the true power. To eliminate this source of error a choking coil was connected in series with the continuous-current supply, thus damping out the high-frequency oscillations in the current. The curves showing the brush loss are given in Fig. 14; and from these curves the losses per pair of brushes at any required speed and current can be read off. The losses increase very rapidly at high speeds, probably owing to the increase of the contact-resistance due to mechanical vibration.

(*c*) To determine the friction and windage losses a continuous-current motor was calibrated for various speeds and was used to drive the Fynn motor by means of a light canvas belt. Readings were taken of the input

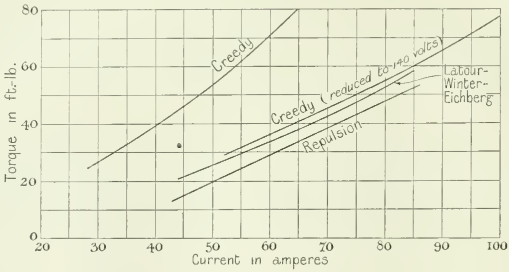


FIG. 13.—Starting Torques.

to the motor when driving the Fynn motor at various speeds, and the difference between the power under these conditions and that required to drive the continuous-current motor light gives the total windage and friction losses fairly accurately. Brush friction was also separated by taking readings with and without the brushes. The friction loss curves are shown in Fig. 15.

(*d*) The exact determination of the separate components of the iron loss in these motors is extremely difficult, as

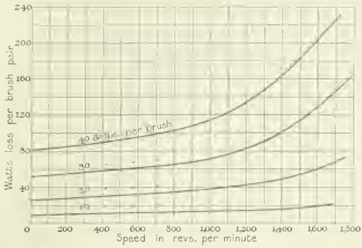


FIG. 14.—Brush Contact and Resistance Losses.

there are so many factors to be considered. With the Atkinson or Fynn connections there will be :—(1) Eddy current and hysteresis losses along the A A axis due to the transformer flux N_1 (with a constant applied voltage the stator loss due to this flux will be constant, but the rotor loss depends on the speed). (2) Similar losses along the B B axis caused by the motor flux N_2 (these losses are a function of the speed). (3) Losses in the rotor caused by

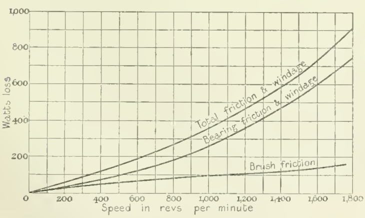


FIG. 15.—Friction and Windage Losses.

the cutting of these fluxes at all speeds except synchronous speed. The fluxes N_1 and N_2 being nearly at right angles in time relation as well as in space, may be considered as forming a rotating field, which will be elliptical except at synchronous speed. At the latter speed the two fluxes are practically equal, and the rotating field will therefore be circular. Now this field always rotates at the speed corresponding to the supply frequency, and consequently if the rotor is running below synchronism there will be a hysteretic drag in the direction of rotation, whilst above that speed this torque is reversed. The rotor iron losses depend on the relative speed of the rotor and the rotating field, so that at synchronous speed they should be nearly zero. In addition to the above there are also the pulsation losses in the stator and rotor teeth, so that it will be seen that an accurate separation of the losses would be exceedingly difficult. For comparative purposes it will be sufficient if the total iron losses are known at any speed.

In order to determine these losses, the motor was driven as in the friction and windage test, and the power supplied to the driving motor was measured. An alternating current at 50 ∿ was led into the A A axis of the Fynn rotor through the current coil of a wattmeter W_1. The pressure coil of this instrument was connected to the terminals of the stator winding S_1 on this axis, and the current in this axis was maintained constant at a fixed value for each test. Under these conditions the wattmeter reads the power supplied minus the copper losses in the A A axis, for the voltage differs in phase by 90° from the flux, since it is induced by the change of the latter.

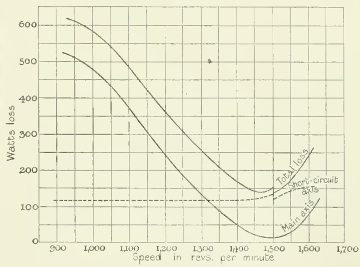


FIG. 16.—Iron Losses.

If the flux were in phase with the current the wattmeter reading would therefore be zero, but since the iron losses cause the flux to lag behind the current the wattmeter measures these losses. The readings have of course to be multiplied by the ratio of the number of secondary to primary turns. It was verified experimentally that the circulating currents in the short-circuited coils also alter the phase of the flux, so that these losses are also measured by the wattmeter. In a similar way the wattmeter W_2 measures the losses along the B B axis. The driving motor supplies the power necessary to overcome the resistance and iron losses in the B B axis, and also the pulsation losses.

The results of these tests are shown in Fig. 16. The total loss is taken as the sum of W_1 and W_2. As a check, the total power supplied to the Fynn motor, *i.e.* the reading of W_1 and the input to the driving motor above that required to drive the Fynn machine unexcited, must be equal to the total iron losses and the resistance loss in the B B axis. The values obtained in this way were found to agree well with those obtained by the first method. At constant voltage the stator iron loss along the A A axis is practically constant, whilst in the B B axis it increases

with the speed, since the flux in this axis depends on the speed. The rotor losses, however, are practically zero at synchronous speed, but increase very rapidly on either side of this speed. This is due to the fact that the rotor losses are largely due to the circulating currents in the short-circuited coils, and therefore for constant density vary as the square of the frequency, the latter being the difference between the synchronous speed and the actual speed.

The accompanying table shows the actual losses in the various circuits, etc., of the motor when running as an Atkinson, Fynn, Latour-Winter-Eichberg, or synchronous motor, and also the separate losses as a percentage of the total losses in each case. Except for the Atkinson connection, in which the maximum output was 3 b.h.p., these are calculated for an output of 6 b.h.p., which is about the normal full load of the motor. In the last three cases it is interesting to observe that the efficiencies are nearly the same, although the losses are made up in rather different ways. In all cases the brush losses form a very considerable proportion of the total, owing to the heavy rotor currents and high speed. The motor should have four brushes per spindle on the A A axis, but only three were available for the tests, and this makes the losses somewhat higher than they would otherwise have been. Friction and windage account for about 40 per cent of the losses. The brush friction forms about one-third of the total friction and windage loss in each case.

		Atkinson. At 3 b.h.p., 1,350 r.p.m.		Fynn. 6 b.h.p., 1,480 r.p.m.		Latour-Winter-Eichberg. 6 b.h.p., 1,320 r.p.m.		Synchronous. 6 b.h.p., 1,500 r.p.m.	
		Watts	Per Cent of Total Loss	Watts	Per Cent of Total Loss	Watts	Per Cent of Total Loss	Watts	Per Cent of Total Loss
Copper losses	Stator ...	480	22	250	16	224	14	230	14
	A A Axis ...	270	13	122	8	162	10	220	13
	B B Axis ...	20	1	46	3	54	3	—	—
	Comp. winding	—	—	40	2	—	—	—	—
	Total ...	770	36	468	29	440	27	450	27
Brush losses	A A Axis ...	300	14	240	15	240	15	468	28
	B B Axis ...	60	3	130	8	136	9	—	—
	Total ...	360	17	370	23	376	24	468	28
Windage and friction ...	Brush friction	115	5	150	9	110	7	156	9
	Total ...	550	26	640	40	540	35	650	39
Iron losses and circulating currents	—	480	21	130	8	200	14	110	6
Total losses ...	—	2,160		1,600		1,560		1,680	
Output	—	2,240		4,480		4,480		4,480	
Input	—	4,400		6,080		6,040		6,160	
Efficiency ...	—	51 per cent		74 per cent		74 per cent		72·5 per cent	
Observed efficiency	—	50 ,,		74·6 ,,		74 ,,		73 ,,	

Single-phase commutator motors may be put to practically the same uses as small continuous-current motors, their only serious rival for small outputs being the single-phase induction motor. Their lower efficiency and higher cost are somewhat of a disadvantage, but their high starting torque gives them a decided advantage for crane and lift work and for driving machinery where high starting torques are required, and they are being manufactured in increasing numbers for these purposes. They are practically the only single-phase motors which can be used for traction work, the plain series type and the Latour-Winter-Eichberg being favoured for this use.

Another great advantage of this type of motor is that it lends itself readily to speed regulation, the speed not being practically restricted to synchronism as is the case with the induction motor. There are several methods of varying the speed of these motors, one of them being to connect an inductance in circuit with the B B axis. The

effect of this is to weaken the motor field, and the machine must therefore run faster in order that the back E.M.F. due to rotation in this flux may attain a sufficient value to restore the equilibrium of E.M.F.'s in the rotor. This method is illustrated in the second test on the Atkinson motor, where the additional inductance in the B B axis caused the speed to rise from 1,500 to 1,900 r.p.m. A resistance cannot be used for this purpose as the current in the B B axis must lag by nearly 90° behind the voltage for satisfactory working, and any additional resistance would naturally decrease this angle. Another method is to supply an extra voltage to the A A axis either by means of a tapping on the stator winding or an auxiliary transformer. This method is analogous to increasing the voltage applied to the armature of a continuous-current motor. A third method is to place an extra coil on the B B axis, connected in series with the brushes on this axis, the coil being connected so that the flux produced by it opposes the motor flux, the effect being similar to that produced by the first method. All these devices tend to raise the speed above synchronism and have been used in practice with good results, but it is more difficult to lower the speed. Any departure from synchronous speed, however, increases the losses in the rotor as the circulating currents and iron losses increase rapidly.

Among the chief disadvantages of these commutator motors are their higher initial and running costs—the commutator of course requiring a certain amount of attention—and their liability to sparking troubles. Sparking on the Fynn motor was noticeable at starting and at heavy loads, probably owing to the fact that soft graphite brushes are used, which although reducing the brush friction and contact losses tend to increase the circulating currents and the amount of sparking; but under normal loads the machine was as sparkless as the average continuous-current motor. The Creedy motor, provided with hard carbon brushes, ran sparklessly at all loads, starting under twice full-load torque with no sign of sparking.

Since the experiments described were made, the authors have assisted in testing a Creedy motor with a variable-speed shunt characteristic, the range of speed being from 600 to 900 r.p.m. This motor is one of a batch designed for the driving of printing presses, but considerations of time prevent the inclusion of the results in this paper.

In conclusion the authors desire to express their thanks to Professor T. Mather of the City and Guilds College for permission to carry out the tests in the laboratories of the College, and to Mr. Creedy for allowing them to publish the results of the tests on his motors.

APPENDIX.

DETAILS OF CONSTRUCTION, ETC., OF FYNN SINGLE-PHASE COMMUTATOR MOTOR. 140 VOLTS, 57 AMPERES, 50 ∿, 1,430 R.P.M.

Rotor.

4-pole series-wound. Number of slots = 39.
Number of segments = 117. Six conductors per slot.
Number of conductors = 234. Size of conductors = 0·15 × 1 cm.
Circumference of rotor = 81 cm. Diameter = 25·8 cm.
Axial length = 12·8 cm.
Laminations per cm. = 21.
Diameter of commutator = 19·3 cm.
Size of slots = 1 × 2·75 cm.
Opening of slots = 0·3 cm.
Gap length = 0·1 cm.

Stator.

Bore = 26 cm. External diameter = 42 cm.
Number of stator slots = 36.
Size of slots = 1·7 × 2·3 cm.
Slot opening = 0·36 cm.
Axial length = 12·8 cm.
Brushes 15·3 cm. apart, measured on arc.

Resistances of windings.

Main stator winding S_1 = 0·103 ohm.
Auxiliary stator winding S_2 = 0·084 ohm.
Compensating stator winding S_3 = 0·022 ohm.
Armature under brushes = 0·025 ohm.
Impedance of B B axis = 2·26 ohm, with a current of 35 amps.
Power factor of B B axis = 0·101, with a current of 35 amps.

Ratios of turns.

$$\frac{\text{Main winding}}{\text{Compensating winding}} = \frac{10}{1}$$

$$\frac{\text{Main winding}}{\text{Rotor along A A axis}} = \frac{1·9}{1}$$

$$\frac{\text{Auxiliary winding}}{\text{Rotor along B B axis}} = \frac{1·04}{1}$$

Brushes.

Morganite. 4 brushes per spindle A A axis.
2 ,, ,, B B ,,
Brush area = 2·1 sq. cm. per brush.

THE ELECTRICAL EQUIPMENT OF COLLIERIES.

By H. S. Ripley, Student.

(*Abstract of Paper read before the* Newcastle Students' Section *5th January*, 1914.)

In the light of previous experience the tendency of present-day practice is towards the adoption of the 3-phase high-tension system as being more economical in working and, with proper precautions, safer and more efficient than a low-tension system.

The author proposes to consider briefly the various branches of the subject under their respective headings.

Switchgear.

The introduction of electricity into coal mines presents three dangers, namely :—

(*a*) Danger of shock to persons through contact with "live" metal.
(*b*) Danger of injury to persons and property through the ignition of explosive gases.
(*c*) Danger of fire.

The recent colliery disasters seem to show that fire involves the greatest danger to human life. To reduce this to a minimum, all gear should where necessary be explosion-proof and fireproof, and in addition to this, automatic means should be provided for immediately cutting off the supply should a leak occur.

The danger of shock to persons through contact with "live" metal may be eliminated by efficiently insulating all current-carrying conductors, and also protecting the same with a metallic covering efficiently earthed.

With the new Home Office Rules now in force it is perhaps not very easy to go astray in regard to switchgear, but it will not be out of place to consider the more important rules which should govern the choice of any particular make of gear :—

(1) There should be a minimum amount of cleaning necessary to maintain the gear in good order.
(2) The insulation should be capable of withstanding any abnormal pressure that is likely to arise.
(3) All circuits should be broken under oil.
(4) The switch should be of substantial construction.
(5) All conductors and contact areas should be of ample current-carrying capacity, and all joints and terminals should be electrically and mechanically sound.

Now the type of gear which best meets the above requirements is the totally enclosed or ironclad type. In this apparatus all the live conductors are enclosed in flame-proof compartments. Flame-proof does not necessarily mean gas-tight. As a matter of fact the joints between the different covers are plain metal to metal, the theory being that should an explosion occur inside the casing the flame becomes effectively cooled by passing through the minute openings left by the machine marks on the face of the joint. The most essential point as regards this switchgear is that it shall be of extremely substantial construction, as the treatment which it will receive in erection and afterwards in operation will be most severe. Provision should be made for completely isolating and locking the switch from the busbars, in order to obviate the danger of its being accidentally closed whilst men are working on that section. The cases containing parts which have to be removed for adjustment or inspection should be so interlocked as to prevent their being removed whilst the parts inside are "live." This point cannot be too strongly emphasized, as fatal accidents have occurred due to its being neglected.

All switches should be fitted with a "free" handle attachment in order that the trip gear may operate irrespective of the handle being held in the closed position, in case the switch should be closed on a heavy overload or short-circuit. Instruments should be avoided as far as possible, especially where these entail the use of potential transformers. An ammeter, preferably of the straight-through type on panels controlling individual motors or transformers, is all that is really required.

Cables.

Cables have now reached a high degree of perfection, and if properly installed and given a reasonable amount of attention they are very safe and reliable. For 3-phase work all main transmission cables should be of the 3-core armoured type. Of these there are several varieties, but, generally speaking, the most suitable is the paper-insulated and lead-covered. It must be mentioned, however, that on account of the absorbent nature of the paper insulation this type of cable requires very careful handling by capable jointers in order to ensure a satisfactory installation.

Rubber-insulated cables are out of the question on account of their cost.

Bitumen-sheathed cables should be used where lead-covered cables would be unsuitable owing to the presence of impurities in the water.

With regard to the lowering of shaft cables, although in reality a very simple matter this is liable to have disastrous results if not carried out in the proper manner. There are three safe methods of procedure :—

(*a*) If the shaft is sufficiently large the cable drum may be slung under the cage and the cable clamped up as the cage is slowly lowered.
(*b*) The drum of cable may be mounted about 100 yards from the mouth of the shaft and the cable lowered in several bights by means of a locomotive. It is important to note that a substantial clamp and chain are required when this method is adopted.
(*c*) The cable may be lowered by lashing it at frequent intervals to a steam crab rope. The crab engine should of course have good brakes.

Immediately after the cable has been lowered, the permanent clamps should be fitted. These may be made

of any hard wood, and should have sloping roofs in order to shed the water. With regard to the method of securing the cable in the shaft, the cable is usually clamped to the inside of the buntings, as this position affords the greatest protection from damage. Another good method is to secure the cable to old winding ropes, if these are available, and to have these ropes suspended in the shaft and securely fastened to the headgear. This method facilitates the lowering and raising of the cable in case of a fault. As soon as possible after erection both the cable and the clamps should be liberally treated with Stockholm tar.

Wherever possible, inbye cables should be taken in the main intake airways, and should be slung or clamped in a position to afford the greatest security from damage. They should always be fixed on the lower side of girders, and never between the girder and the roof. Where there is a danger of a fall of stone, the cables should be slung on flexible suspenders in order that they may break away readily should a fall occur.

Earthing.

The most efficient way of safeguarding against persons receiving shocks is, as mentioned previously, to cover all "live" conductors with an earthed metallic covering.

As to the method of obtaining an efficient earth :—Two earth-plates, approximately 3 ft. square and 30 ft. apart, should be sunk at the surface and placed vertically in the ground at a depth of about 6 ft., being well packed on all sides with crushed coke. The place selected should be as wet as possible. Should the ground be of a very dry nature a wrought-iron pipe should be buried alongside the plate in order that the latter may be occasionally flushed with water. Great care must be taken to ensure a mechanically sound connection to the earth-plate ; and brass, not iron, bolts should be used. Too much stress cannot be laid on the importance of having a sound mechanical earth connection at the surface, but in addition to this a further earth-plate should be sunk at the extreme end of the cables' inbye, the connection being securely clamped to the armouring. This tends to ensure the whole of the armouring being at earth potential irrespective of the condition of the intervening ground. Where possible, all motor and controller frames, etc., should be earthed directly on to the armouring of the cable, and the practice of earthing pieces of apparatus in series should be avoided.

A rather interesting comparison between the combined conductivity of the lead sheath and double armouring and the conductivity of the cores, is given below. These figures

Cable	Equivalent Conductivity of Lead and Armouring. Copper = 1
0·025 sq. in. 3-core, 2,875 volts	2·6
0·05 ,, ,, ,, ,,	1·5
0·1 ,, ,, ,, ,,	0·8

were obtained from samples of cable recently supplied to a local colliery, and they may be taken as being approximately correct for all makes of cable.

Protective Gear.

On a completely insulated system complete protection can be obtained by having tripping devices in two phases only, as any fault current or overload passing through the third phase must return through the others and therefore through the trip coil. When this system of protection is used it is necessary to install earth detectors in order to indicate at all times the state of the insulation. On low-tension circuits an earth detector consists of a milliammeter connected in series with a high resistance between the line and earth. On 3-phase systems the resistances are star-connected and the earth detector is inserted between the middle point and earth. The scale is usually calibrated to indicate the insulation resistance in ohms, together with the amount of current flowing to earth. On high-tension circuits it is necessary to use a static earth detector. This consists of a differential static voltmeter, the fixed vanes of which are connected to two phases and the movable parts connected to earth. For 3-phase systems two instruments are required, and are usually enclosed in one case. The scales are arranged with the zero mark in the centre ; and with no fault on the mains the needles hang vertically. Should a fault occur on one phase, the needle is deflected to the left or right, owing to its being repelled from one or other of the metal vanes.

With the neutral point of the system insulated, it is possible to keep the plant running with a leakage on one phase. It is in this that the danger lies, as although the earth detector may indicate that the insulation is approaching a dangerous condition, there is always the risk of the warning being neglected until the apparatus finally breaks down, with perhaps serious consequences.

On high-tension circuits with the neutral point earthed it is possible by the use of current transformers to obtain independent control of overloads and earths. The method consists of inserting a sensitive relay or trip coil in the return circuit to the three current-transformer secondaries This relay or trip coil will then operate on all faults to earth. The overload protection may consist of series trip coils in two phases, or a time-limit overload protection worked from the current transformers. A drawback to the use of the sensitive relay is that it requires a separate source of supply to energize the trip coil of the switch. This entails the use of potential transformers, which are by no means desirable in mining switchgear. The alternative, of course, is to allow the actual current induced by a fault to earth to operate directly on the trip coil of the switch. Owing to the fact that quite an appreciable amount of energy is required to trip the switch, the setting will be less sensitive.

With regard to overload protection, series trip coils should be used whenever possible, as they are very simple in operation and give very little trouble. They are now fitted by several manufacturers for voltages up to 3,000, and are usually encased in the hood of the switch. They are generally calibrated between normal load and twice full-load. Should a time-limit device be required, this can be arranged by the use of oil dash-pots. No-volt releases should be avoided. They are very apt to operate on momentary fluctuations in the pressure, causing unnecessary trouble owing to switches tripping at an inopportune moment. Should the pressure decrease to any great extent and suddenly return to its normal value,

the overload gear will be found sufficient to protect the plant from any damage.

Motors and Controllers.

The ideal motor for underground use would seem to be the squirrel-cage type. Unfortunately, however, most of the operations requiring large power also require a large torque at starting, and for these the squirrel-cage motor is unsuitable. However. a properly designed slip-ring motor usually gives little trouble, and assuming that it is suitably housed and is given a reasonable amount of attention, it is a sound piece of apparatus.

Probably one of the most important points in regard to motors is the bearings, and special attention should be given to these. Preferably they should be of the self-aligning type, with ring lubrication. The more important point, however, is their size, and no motor should be accepted with bearings smaller than $2\frac{1}{2}$ times the diameter of the shaft.

Starting and controlling devices for large motors require to be of very sound mechanical construction. The liquid type is undoubtedly the most suitable, both as regards first cost and operation. Uniform acceleration is obtained, and also an indefinite number of speeds are available between maximum and minimum limits. Several excellent totally enclosed starting switches are now on the market, and as long as attention is given to mechanical details it is not possible to go far wrong.

Controllers for haulages and winders are also made of the liquid type. As a rule the stator reversing switches are fixed on the end of the controller, and the mechanism is such that the reversing switches are interlocked with the rotor control gear and operated from the same shaft. In the smaller sizes the electrodes are operated directly from the driver's lever, but in the larger sizes the masses are too great for hand operation and the design is somewhat different. The apparatus usually consists of two tanks mounted one above the other, the upper tank containing three stationary electrodes and a movable sluice gate, and the lower one the supply of electrolyte. A small motor-driven centrifugal pump raises the electrolyte from the lower tank into the upper, and with the sluice gate in its lowest position the electrolyte immediately returns to the lower tank. When, however, the sluice gate is raised, the liquid is retained in the upper tank and gradually submerges the electrodes, thereby diminishing the resistance between the slip-rings of the motor. It will be seen that as the pump is delivering a constant quantity of water a certain maximum acceleration of the motor cannot be exceeded. It can, however, be adjusted by placing a stop valve in the delivery pipe of the pump and regulating the quantity of water pumped.

Lighting.

All underground lighting should preferably be at pressures below 125 volts, as this obviates the necessity of earthing lampholders and fittings. The high pressure may be stepped down directly to the lighting pressure, or if medium pressure is required for small motors an auto-transformer will be suitable for further reducing the pressure. It is essential that one pole of the secondary winding should be earthed in order to avoid the possibility of the lighting wiring becoming charged with a high pressure, owing to the failure of the insulation between the primary and secondary windings of the transformer.

Coal Cutting.

The practice of working coal by machinery has grown and will continue to grow more important as time advances, owing to the fact that most of the big coal seams in this country are becoming exhausted, with the result that the thinner seams, in which it is difficult for men to work, are by necessity having to be worked.

Coal-cutters may be driven either by compressed air or by electric motors, but of the two methods motor driving is better adapted for the purpose. The efficiency of compressed-air transmission is low, being from 20 to 25 per cent as against 65 to 75 per cent with electric transmission. Another important factor is the small space required for a motor compared with that required for a compressed-air machine of the same power. Against this, of course, must be put the additional risk attached to the use of electricity at the coal face. Happily, however, suitable gear has been developed, which has reduced this danger to a minimum.

High pressure is, of course, out of the question and it is necessary to install oil-immersed transformers in buildings as near the coal face as possible, there stepping down to medium pressure. From these places the current is transmitted by 3-core armoured cables to a gate-end box, which is situated at the entrance to the seam that is being worked. This box is of flame-proof construction and contains a 3-pole oil switch fitted with fuses or overload coils. The construction of the box is such that it is impossible to remove the cover until the switch is open. From here the current is transmitted by a flexible trailing cable to the starting switch of the motor. Trailing cables are as a rule of the 4-core type, one core of which is used as an earth conductor. Several varieties of trailing cables are on the market, some insulated with rubber and sheathed with bitumen, and others with a very durable quality of rubber known as "cab-tyre sheathing."

A 4-pin plug connects the trailing cable to the gate-end box and the motor, the earth pin being internally connected to the framework of the box and the motor. An interlocking arrangement is fixed by which the plug cannot be engaged or withdrawn whilst the gate-end switch is closed, also the pins are so constructed as to make it impossible accidentally to push the earth contact into a live socket.

As to the coal-cutter motor itself, this is of the totally enclosed type and drives the cutter through gearing. Motors up to about 30 h.p. are usually of the squirrel-cage type and are controlled by compensators For larger powers motors with wound rotors are used, and are controlled by rotor resistances of the grid type.

Winding.

The application of electric power to winding has up to recent years been limited, probably owing to the fact that very expensive and economical steam winders are installed at many collieries, and that the advantages of electric winding over steam winding have not been sufficiently understood to bring about a change. The development of power companies that can supply electrical energy in bulk at very reasonable rates has, however, been

the means of bringing about several changes in different parts of the country, with very gratifying results.

A correct comparison of the advantages of electric over steam winding depends on the various factors and circumstances affecting each case, and the author regrets that the time at his disposal is too short to go into these very fully. It may be said, however, that the main advantages of electric winding are :—

(1) Ability to run odd trips at any part of the day or night without the necessity of warming up cylinders, etc.
(2) More even turning moment.
(3) Regenerative braking possible.
(4) Simpler and more economical control.

The author proposes to describe briefly the more important systems of winding now in use.

Direct-coupled System.

The first system consists of a 3-phase induction motor, direct coupled or geared to the drum and controlled by switches and resistances in the stator and rotor circuits of the motor. The controller is usually of the liquid type described earlier in this paper. A geared winder has the advantage of allowing a higher-speed motor to be used, which is an important point where the power factor and the first cost of plant are concerned.

The great advantage of this system of winding is its simplicity and also its low first cost. The overall efficiency is also somewhat higher than that of other systems. Against this it may be said that the peak load caused by the starting of large winders of this description only permits them to be connected to systems with plenty of reserve plant ; also, the control being effected by varying the rotor resistance entails considerable rheostatic losses.

Westinghouse Converter Equalizer System.

This system has been developed by the above company for the purpose of reducing the heavy current taken from the mains when large direct-coupled winders are started. The main equipment is similar to the one previously described. In addition, however, the 3-phase mains are fed through transformers to a rotary converter, the energy of which is supplied to a shunt-wound motor fitted with a heavy flywheel. The field of the continuous-current motor is adjusted by means of an automatic regulator. Under normal conditions with the winder motor at rest the converter set is running at constant speed ; when, however, the motor is switched in and begins to move, a heavy current is taken from the mains, causing the automatic regulator to cut out resistance from the field circuit of the continuous-current machine, and the latter to act as a generator and its speed to drop. The kinetic energy of the flywheel now drives it as a generator, and its electrical energy is supplied to the rotary converter ; it is here converted into alternating current, which flows through the transformers to the line, helping to supply the winder motor. When the load falls below the average the action is reversed and the regulator inserts resistance into the field circuit of the continuous-current machine, which then acts as a motor and, driven by the rotary converter, brings the flywheel back to its normal speed. The automatic regulator is fed by series transformers in the main leads to the winder motor, and it will thus be seen that by suitably arranging these transformers the energy taken by the winder from the generating station can be kept at an average value.

The advantages of this system of equalizing are that a breakdown of the converter does not necessitate a stoppage of the winding plant, and also that the rotary converter being a synchronous machine can be made to operate at leading power factor and so compensate for the lagging component of the induction motor.

Ward Leonard and Ilgner Systems.

In these systems instead of the winder motor being directly connected to the supply mains, there is interposed between the two a motor-generator, the motor taking energy from the mains and the generator supplying energy to the winder motor. The field magnets of the winder motor are separately excited and the field is of fixed direction. The field magnets of the generator are also separately excited, but with a long-range rheostat in circuit, by which the magnetism can be raised from zero to a maximum and reduced again to zero, or it can be reversed and raised to a maximum in the opposite direction. On starting, the voltage of the generator is raised until sufficient torque has been exerted by the winder motor to overcome the load. As the winder motor accelerates, the voltage of the generator is raised further, so as to maintain the full current as long as may be desired. The turning moment can with equal ease be reduced by lowering the voltage of the generator, and a reversal of rotation is obtained by reversing the direction of the generator field.

In order to equalize the load the motor-generator is fitted with a heavy flywheel. This comprises the Ilgner system of winding.

At the start of a wind the power required to start and accelerate is considerably more than is required when the motor-generator is running light. The demand upon it causes its speed to drop, the flywheel immediately giving up part of its kinetic energy and assisting to drive the generator. When, however, the load falls, the kinetic energy of the winder, drum, etc., begins to drive the motor, which becomes for the time being a generator and returns current to the motor-generator, causing the generator to act as a motor and to bring the flywheel back to its normal speed.

The chief advantage of this system is the ease and economy of control. Any speed from inching to full speed can be obtained by simply varying the field strength of the generator. The disadvantages are the higher first cost, due to three machines being installed instead of one, and also the lower overall efficiency.

The C.M.B. Converter System.

In this system the method of control is similar to the Ward Leonard, but embodies certain modifications. The equipment consists of a rotary converter and a variable-voltage generator coupled on one shaft, and also a main winding motor. The generator is connected in series with the rotary armature and may be excited so as to oppose or assist its voltage. It is also provided with a

special series winding in opposition to the shunt field winding, and by this arrangement the resultant field of the generator bears a relation to the current supplied to the winder motor, which is thereby limited.

The heavy torque required by the winder motor at starting is obtained by employing two shunt windings, one of which is constant, whilst the other varies with the speed of the motor. The gear is controlled by means of a regulator in the field circuit of the generator and by a reversing switch in the motor circuit. Whilst running light, the voltage of the generator opposes that of the rotary converter. On starting, the main switch is closed and the regulating switch is operated, by which the field of the generator is reversed. As the winder motor is accelerating, the combined voltage of the rotary converter and generator is building up, and a current is supplied to the motor, which, in conjunction with its strong field, causes the motor to exert a heavy torque until the field of the generator is reduced.

Conclusion.

In conclusion, it is hardly necessary to emphasize the necessity of using the best possible gear that can be obtained, as everybody will admit that a coal mine is the very last place in which imperfect gear should be installed. Simplicity of design and mechanical strength are the main features of good equipment, and complicated apparatus should be avoided. As regards the maintenance of the plant, cleanliness is of course the chief point, and a system of routine inspection work should be established. If this be rigorously carried out there should be very little trouble due to breakdowns, and the reputation of electricity as being the most efficient method of transmitting power in collieries will be maintained.

DISEASES OF TRANSFORMERS.

By J. L. Thompson, M.Sc., Student.

(*Abstract of Paper read before the* Manchester Students' Section *17th March*, 1914.)

Although transformers are the most reliable of electrical machines there are several causes from which troubles may arise. The major troubles are :—(1) Absorption of moisture ; (2) excessive heating ; (3) short-circuits ; (4) abnormal voltage strains.

Absorption of Moisture.

Before putting transformers of 6,000-volt rating and over into service it is essential that they should be dry and that the oil in which they are immersed should also be dry. The state of dryness can only be roughly estimated, and that by an intimate knowledge of its history. The insulation resistance of a transformer will give an approximate indication of its state of dryness, but any values obtained should be taken with reserve.

If drying out is considered necessary, the insulation resistance values taken at different stages of the heating and plotted against the temperature will give a very valuable indication as to when the transformer is in a safe condition. As the temperature of the transformer rises the insulation resistance will fall, as shown by (*a*) in Fig. 1. This drop will continue until the temperature reaches 90–95° C. After this drop, the resistance will remain constant for a period of time, short or long according to the quantity of moisture that is present. When most of the moisture has been removed the resistance again drops, as shown by (*b*) in Fig. 1, but it rapidly rises again as shown by (*c*). At any point a moderate way up on section (*c*) the transformer may be said to be dry.

Due to breathing action moisture may be absorbed by transformers in climates where there is a great variation in temperature or where steam is prevalent in the atmosphere. This trouble can be eliminated by using air-tight tanks, or by fitting the tank with breathing apparatus. In general when moisture-proof transformers are required the first alternative is followed, a tank constructed of boiler iron with welded seams being used.

Water-cooled transformers will accumulate moisture by the condensation of any moisture in the atmosphere on the copper cooling coils (owing to the high heat conductivity of copper) down to the level of the oil. This can be guarded against by lagging the pipes down to the level of

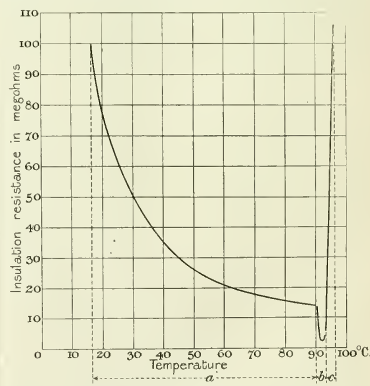


Fig. 1.—Insulation Resistance Characteristic with Temperature.

Period of time for section *a*, 10–15 hours.
" " " *b*, 1–5 days.
" " " *c*, 10–12 hours.

the oil, or by sealing the spaces round the pipes where they enter the tank. Periodic examination of the cooling coils should be made in case corrosion has taken place due to acid impurities in the water. Seamless tubes should be used as they are less likely to develop faults than welded tubes.

With force-cooled transformers moisture troubles are rare, since such transformers are in general air-tight and the oil is forced through the cooling apparatus under pressure.

Samples of oil, drawn from the bottom of the tank, should be taken periodically from transformers and the breakdown voltage of the oil should be tested. If this voltage falls much below 30,000 across a 0·2-in. gap, the oil should be dried out. Although failures due to moisture are not of frequent occurrence, yet all things being equal, any precautions taken will be repaid by the long life and the continuity of service of the transformers.

Excessive Heating.

Oil-immersed, self-cooled transformers are in general designed to give a normal temperature rise of 40–50° C., but this will be materially increased if the room or chamber in which they are installed is not sufficiently ventilated. If there is poor ventilation the transformers will operate as if surrounded with lagging, and before the losses can be dissipated a rise in temperature of 45° C. is necessary above that of the surrounding air, which may be 30–35° C., with a result that the working temperature will be 80–85° C., that is to say near to the danger zone. For efficient cooling, the chambers should be uniformly ventilated about the level of the floor and the roof. If several self-cooled transformers are working in the same room they should be spaced 24–30 in. apart, or they will serve as lagging to one another.

Heavy and frequent overloads result in high temperature rises, and if sufficient time is not allowed between these overloads for the accumulated heat to be dissipated, this high temperature will be maintained.

Water-cooled transformers are used to deal with large outputs and where adequate ventilation cannot be obtained. Since the heat generated is dissipated by external means, the ventilation of the chamber will not affect the working temperature. The thermometers used for temperature indication should be placed well away from the cooling coils, and well down under the oil. This type of transformer should never be operated without water circulating through the cooling coil; even on open circuit the water should not be cut off, as the iron loss in itself is sufficient to raise the temperature of the oil and windings to a dangerous value. The temperature of the entering water should never exceed 25° C., since the transformer is designed with a certain temperature rise above the temperature of the entering water. If the water, when used, can be run to waste, then the initial temperature can be easily kept within the required value. If the quantity of water is limited, the auxiliary chamber must be well ventilated or its temperature will rapidly rise. The quantity of water flowing must be kept up to the specified amount, or overheating will occur.

Decreasing the flow of water increases its temperature rise in inverse ratio, and the transformer temperature is raised half this amount; on the other hand, increasing the flow decreases its temperature in inverse ratio, and lowers that of the transformer by half this amount. If the flow is increased 50 per cent, the transformer temperature is reduced 5 per cent. If the flow is decreased 50 per cent, the transformer temperature is increased 15 per cent. From this it follows that the cooling coils should be clean inside, so as not to restrict the flow of water. As with self-coöled transformers, excessive overloads are dangerous, since the dissipation of heat depends on the natural circulation of the oil. With large transformers the temperature is kept within the required limits by forced circulation of the oil.

Overheating from whatever cause results in (1) deterioration of the insulation; (2) increase in the copper losses, and therefore increased running cost and lower efficiency; (3) sludging and disintegration of the oil; (4) ageing of the iron, with increased losses and running costs, and lower efficiency; (5) fire risks due to the inflammable nature of oil vapours.

Mechanical Strains.

The author has dealt so far with diseases of slow growth, and he now passes on to those of instantaneous growth.

The mechanical force exerted on transformer windings under normal conditions is small, and is amply taken care of by the rigidity of the windings. The force exerted on the end coils of a 2,350-k.v.a. 25-∿ single-phase shell-type transformer which came under the author's notice only amounts to 0·24 ton. In a transformer having an impedance of $2\frac{1}{2}$ per cent a current equal to 40 times full-load current will flow in the case of a short-circuit if the full voltage is maintained across the primary windings. This current will result in a force 1,600 times that under normal full load; and as it may amount to hundreds of tons, it is therefore destructive.

The causes of excessive currents are:—(*a*) Accidental short-circuits; (*b*) switching.

Accidental short-circuits occur through incorrect connections, the falling-out-of-step of synchronous machines, bad synchronizing, or a flash-over on the continuous-current side of a rotary converter. The magnitude of the short-circuit current is dependent on the total impedance of the short-circuit and on the voltage that can be maintained. If the voltage maintained be only half the line voltage, then the force exerted would be one-quarter of that which would be present with full voltage.

Transformers which can safely withstand a short-circuit at a distance, *i.e.* with a long transmission line, or a high-reactance machine situated between the fault and the transformer, might be instantly destroyed if the short-circuit had occurred directly across the secondary terminals.

Until recently good regulation was considered essential, and to obtain this transformers were designed with low reactance. However, with the growth of the output of modern supply systems this low reactance has become a danger, since it is now possible to maintain full-line voltage in the event of a short-circuit. The short-circuit current can be limited to a safe value by increasing the reactance internally or externally. With transformers of 1,000 k.v.a. and upwards it is now usual to include 6–8 per cent reactance for protection.

As an example of the reduction of the mechanical forces

on short-circuit due to increased reactance, let us consider the 2,350-k.v.a. transformer already referred to.

A. Coil grouping existing in transformer.

B. ,, ,, rearranged to give higher reactance.

A :—L.L L. H.H.H H.H.H. L.L.L.L.L.L. H.H.H.H.H.H. L.L.L.

B :—L.L.L.L.L.L. H.H.H.H H.H.H.H.H.H.H.H. L.L L.L L.L.

	Grouping	Reactance (per cent)			Impedance (per cent)	Max. Force on End Coils (outside core) with Line Volts at Short-circuit
		Internal	External	Total		
1	A	5·42	—	5·42	5·55	75 tons
2	B	19·25	—	19·25	19·26	24 ,,
3	A	5·42	4·1	9·52	9·7	24 ,,
4	A	5·42	8·0	13·42	13·43	$12\frac{1}{4}$,,
5	A	5·42	13·83	19·25	19·26	6 ,,

From the above it will be seen that by using grouping B instead of A the reactance is increased $3\frac{1}{2}$ times, and the mechanical stresses are reduced to less than one-third. If external reactance were used on the primary side, the same reduction would be obtained by increasing the total reactance to 1·8 times its original value, or the forces have been reduced inversely to the (increase in reactance)^2. If

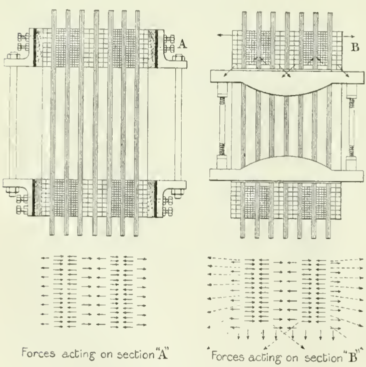


FIG. 2.—Bracing of Transformer Windings.

the external reactance were further increased so that the total equalled that of B, then the forces would be reduced to one-twelfth, as against one-third with B.

(Items 2 and 5.) From these it will be seen that external reactance is more effective and efficient than internal reactance. External reactance, unless inserted in the primary circuit, will have no effect in allaying destructive forces occurring from breakdowns of the insulation in the windings. Further, the extra capital cost that external reactance necessitates must be balanced against its utility when other means are available for doing the same work though not in such an efficient manner.

Though the current may be limited, the forces still exerted are destructive to the windings if the latter are not

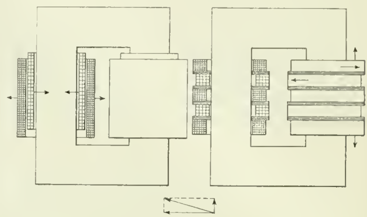


FIG. 3.

mechanically braced. The forces act in two directions: a repulsive force between the coils, and a compressive force in the plane of the coils. These repulsive forces are overcome by the core in shell-type transformers, and by the bracing at the top and bottom of the coils as shown in Fig. 2. The forces in the plane of the coils can be reduced to a large extent by making the sections and lengths of the primary and secondary coils approximately equal. The bracing used for resisting this force is also shown in Fig. 2.

With core-type transformers similar forces are experienced.

With concentric windings, if the coils are symmetrical and coaxial, the forces in the axial direction are eliminated, but by reason of tappings, uneven winding, etc., this cannot be attained. The forces in a radial direction are the more effective, and are resisted by clamping the coils at the top and bottom, by taping the windings, by the rigidity of the winding, and by packing out the coils rigidly from the core. Fig. 3 shows these forces acting on a core-type transformer due to eccentricity of the windings.

The following is further proof that external reactances are more effective than internal reactances. Internal reactances can be increased in various ways. If the increase is attained by reducing the number of groups, the forces at short-circuit will not necessarily be within a safe value. This is so because these forces depend inversely on the square of the number of groups, as will be seen from the following equations:—

For equal grouping—

Mechanical stress

$$= \frac{(\text{No. of turns})^2 \times (\text{Current})^2 \times K}{(\text{Length of leakage path})^2 \times (\text{No. of groups})^2}.$$

For dissimilar grouping—

$$\text{Mechanical stress} = \frac{(\text{No. of turns})^2 \times (\text{Current})^2 \times K}{(\text{Length of leakage path})^2},$$

where K is a constant.

From the above it will be seen that for low mechanical stress high reactance must be obtained by a large number of groups and a large leakage path, hence an expensive transformer. If, however, the number of groups is kept large, and the current is reduced by external reactance, a low stress will be obtained as in the example.

Magnetic shunts are frequently used for obtaining high reactance for regulation purposes when the transformer is feeding a synchronous converter. This method, however, is of little use for limiting short-circuit stresses, since the iron soon becomes saturated and loses its effectiveness.

Excessive currents are sometimes experienced when switching a transformer on to the line, even with the secondary open-circuited. This will occur if the switching occurs at a point where the magnetic field should have considerable value. This current may reach many times full-load current but is not dangerous; it throttles the primary windings, however. This current is dealt with in switching by using a resistance in series until the switch is closed, the resistance then being cut out. The current is thus limited and all instruments on the primary line are protected.

Voltage Strains.

With the advent of high voltages, high-tension transformers have to be designed to withstand abnormal voltages as well as the normal pressures. Abnormal voltages result from:—(1) Switching; (2) instantaneous short-circuits; (3) arcing earths; (4) lightning; (5) constant induction.

(1) The maximum pressure rise which can occur under normal switching is limited to twice the normal voltage, and this occurs at the end of the line where the switching impulse adds itself to the line voltage. The result of connecting a "dead" transformer to the line is at the first instant to put full voltage across the end-turn, the pressure being distributed at the next instant over two turns, and so on; thus in successive instants the voltage is distributed over more turns. This impressing of the line volts on the first turns occurs with all transformers; but at pressures up to 3,000 volts it is not dangerous, since the normal insulation between turns is sufficient to withstand this voltage for instantaneous periods. For higher voltages the end-turns must be reinforced. Fig. 4, which illustrates a section of the top coil of a 60,000-volt transformer, is an example of reinforcement.

The only alternative to reinforcement is the use of a choke coil in series with the primary winding. If this coil has 30 turns, and each has the same choking effect as one transformer turn, then the first transformer turn becomes the 31st turn to receive the voltage, which is 1/31 of the line voltage. It is advisable to use these coils on overhead transmission systems and not on cable systems, owing to the risk of resonance with the latter.

(2) The same voltage strain exists between the end-turns when transformers experience temporary short-circuits which cause the voltage to fall to zero, the pressure being first withdrawn from the end-turns, then from the last two turns, and finally from the first turn.

Instantaneous short-circuits occur at the instant when a cable of high electrostatic capacity is connected to a transmission line; the terminal pressure falls to zero, and assumes normal conditions again within 1/1000 second.

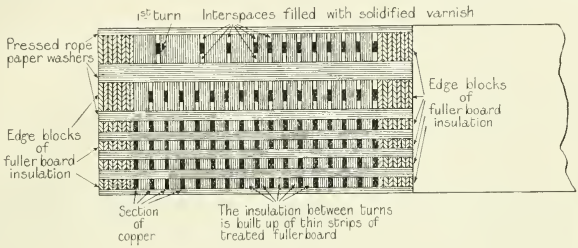


Fig. 4.—Section of Top Coil of a 60,000-volt Transformer.

(3) Instantaneous short-circuits are also caused by arcing earths on earthed systems. These earths may occur at insulators on overhead lines due to faulty porcelain, or dirt, ice, or snow, at cable joints with bad connections, at transformer bushings, or at generator coils.

When an arcing earth occurs on one phase of an unearthed 3-phase system, the arc always takes place at maximum potential, and the potential of the other phases rises from "star" to "delta" potential above earth; and since this earthing is sudden, the voltage will rise to double the normal value. This voltage can only be resisted by designing the insulation to earth to withstand it, and since the usual factor of safety is 4, this insulation may be taken to be sufficient.

Arcing earths, lightning, and switching, all produce high-frequency waves which travel along the transmission system to and from the source of supply. These waves are responsible for many insulation failures on high-voltage transformers, and as they cannot enter into transformer windings unless the windings have a high electrostatic capacity, they are only dangerous to the internal windings of transformers for 50,000 volts and upwards. With lower

voltages they are limited to the end-turns, which are protected by reinforcement.

If the high-frequency travelling wave is due to one impulse, viz. switching, the high voltage will rapidly die down. If, however, successive impulses occur, due to arcing earths or lightning discharges, these successive waves may build up to very high destructive values. This building up of a travelling wave is termed a standing wave, and occurs at a point in the winding which offers direct opposition to the high-frequency wave. An inductance offers a dead resistance to a travelling wave, so that if on the line side of the transformer an inductance or choke coil is inserted in series, the standing wave will form on the line side of that inductance; a horn-gap is placed at this point and the high voltage discharges across it to earth.

This discharge is not allowed to go to earth direct, as it would earth the transmission system, but it is discharged through an energy-absorbing device, known as an electrolytic lightning arrester. Arcing earths at transformer bushings have now been practically eliminated since the adoption of the condenser terminal for high voltages, which produces a more even electrostatic field to earth and therefore a lower potential gradient.

Constant Induction.

There is always a danger of insulation failures on the low-tension side of high-voltage transformers working on an unearthed system. This danger is due to the fact that the transformer windings have a capacity between each other and also a capacity to earth. If an earth of any kind takes place on the high-tension side of a transformer, then provided the capacity of the low-tension winding to earth is appreciable compared with its capacity to the high-tension winding, the low-tension winding may assume a very high potential above earth, and its insulation from earth may thus be destroyed. To guard against this occurrence the low-tension windings should be earthed direct or through a spark-gap, or else be connected to earth through a condenser having a much higher capacity than that existing between the primary and secondary windings. The same result occurs if one high-tension terminal is disconnected from the high-tension line before the other.

THE POSSIBILITIES OF ELECTRIC TRACTION ON RAILWAYS.

By J. L. Moffet, B.Sc., Student.

(*Abstract of Paper read before the* Manchester Students' Section *3rd March*, 1914.)

The application of electricity to the haulage of vehicles has been under consideration for many years. In competition with the horse it made rapid progress on tramways, but up to the present is has not been a serious rival of the steam locomotive.

It was only with the introduction of the modern steam turbine that any decided saving in running expenses could be claimed for electric traction, and even now it is only for heavy suburban traffic that it is accepted as a commercial proposition, at any rate in this country.

The main items in which a saving can be effected by electrification are :—

(1) Fuel per unit of energy.
(2) Total fuel (owing to the reduction of the weight of the locomotive portion).
(3) Repairs of locomotives.
(4) Cleaning of locomotives.

Against these have to be set the increased cost due to :—

(*a*) Interest on extra capital expenditure.
(*b*) Extra depreciation.
(*c*) Extra staff at power station and sub-stations.
(*d*) Fuel for extra losses in transmission, converting machinery, track, rheostats, and motors.

In electric traction a smaller amount of fuel is required per unit of energy, since it is not found practicable to construct the steam locomotive to work with a condenser. The difference that this makes is shown in Table 1, which gives the steam consumption per i.h.p.-hour for a perfect engine when exhausting into the atmosphere and when exhausting into a vacuum of 28 in. A reduction of about 80 per cent is shown in the latter case, which is about the saving effected in practice.

Table 1.

Steam Consumption.

	Non-condensing	Condensing
Steam pressure (gauge) per sq. in.	180 lb.	180 lb.
Superheat	100° F.	100° F.
Vacuum	Nil	28 in.
Perfect plant—		
Steam per h.p.-hour...	12·8 lb.	7·1 lb.
Coal per h.p.-hour (13,000 B.Th.U.)	1·1 lb.	0·61 lb.
Actual coal per h.p.-hour (average)...	2·5–6 lb.	1·5 lb.
Efficiency	45–18%	41 %

It is difficult to estimate the saving in repairs, as so few figures for electric locomotives are available. From Table 2 it will be seen that greatly different values are given, even for the same installation, by various authorities, probably due to different items being included. It would add greatly to the value of most published data if more care were taken in each case to specify exactly what is included in the figures given. In applying American figures to English railways it must be borne in mind

that the repair bill is largely made up of wages, and that these are very much higher in America than they would be here. The repair bill also largely depends on the type of load to which the equipment is subjected. The Lancashire & Yorkshire figure of 1·65d. per mile is for equipment performing one of the heaviest schedules in the world, viz. 30 miles per hour with a stop on an average every $1\frac{1}{3}$ miles. This means that the motors are overloaded to about $1\frac{1}{2}$ times their one-hour rate every two or three minutes, and consequently the wear and tear is very much greater than in the cases subsequently considered in this paper. The number of breakdowns, and therefore also the repair bill, have also been largely reduced

System.

It is not the author's object in this paper to discuss the relative advantages of alternating current and continuous current. The values given are based on a high-tension continuous-current system, with a third rail in suburban districts and an overhead conductor on long straight runs in the country. The voltage on the third rail is taken as about 1,500, and on the overhead conductor as 3,000, the motors being run in parallel at 1,500 volts, and two in series in the case of 3,000 volts. If either a single-phase or 3-phase alternating-current system would prove more economical, then it would be so much more to the advantage of electric traction.

Table 2.

Repair Cost of Electric Locomotives.

Authority	Horse-power	System	Railway	Repairs per loco-mile
Lydall*	800	C.C. 600 v.	Metropolitan District	0·5d.
	2,000	C.C. 600 v.	New York Central	1·5d.
	4,000	C.C. 600 v.	Pennsylvania	3d.
	600–1,500	single-phase	New York, New Haven, & Hartford	$\frac{3}{4}$–3d.
Parodi †	1,000	single-phase	New York, New Haven, & Hartford	3·4d.
	2,000	C.C. 600 v.	New York Central	1·6d.
	2,000	C.C. 600 v.	Pennsylvania	3·3d.
Aspinall ‡	600	C.C. 600 v.	Lancashire & Yorkshire (motor coach)	1·65d.§

* *Journal I.E.E.*, vol. 51, p. 739, 1913.
† *Ibid.*, p. 526, 1913.
‡ *Institution of Mechanical Engineers, Proceedings*, p. 423, 1909.
§ Electrical equipment of motor coach only.

in recent years by the use of mica as an insulator in motors, controllers, etc.

From Table 2 a cost of $\frac{3}{4}$d. per mile would appear to cover the repair costs of a 600-h.p. continuous-current locomotive, but in order to be well on the safe side $1\frac{1}{4}$d. per mile has been taken in all calculations.

More definite figures are available in the case of the steam locomotive. Table 3 gives the cost of repairs and renewals

Table 3.

Repair and Renewal Cost per Loco-mile for Steam Locomotives during Second Half of 1912.

L. & N.W.	G.W.	Midland	N.E.	L. & Y.	G.C.	G.E.
3·1d.	3·9d.	3·8d.	4·8d.	4·45d.	4·7d.	3·9d.

for a few English railways for the second half of 1912. An average figure is 4d. per mile. If the cost of renewals be taken at 4 per cent of the cost of a locomotive, equivalent to an 18 years' life, the cost of renewals works out at 0·9d. per locomotive-mile, assuming the first cost to be £1,900 and the mileage to be 20,000 per annum. The cost of repairs is thus 3·1d. per locomotive-mile, and this has been taken as 3·25d. for goods, 2·75d. for passenger, and 3·25d. for suburban work.

Cases Considered.

Railway traffic can be divided into three main heads :—

(*a*) Express passenger traffic ; with which might be classed express goods.

(*b*) Goods traffic.

(*c*) Suburban or stopping trains.

In order to find with what density of traffic the saving effected in running costs will exceed the cost of interest and depreciation on the extra capital expenditure incurred, a case has been worked out for each class of traffic. The fuel consumption is shown in Table 4, and the energy for each case is calculated from the train resistances given by Mr. Aspinall.* The electric locomotive resistance is based on figures for the New York Central Railroad given by Mr. A. H. Armstrong in the discussion on Professor Carus Wilson's paper on "The Predetermination of Train Resistance." † The coal consumptions per i.h.p.-hour in the case of the steam locomotive are based on modern test figures, and are lower than average practice. The figures for the electrical case are based on the steam consumption with modern turbines, on about $\frac{2}{3}$ full load, in combination with boilers having an average efficiency of 70 per cent.

* J. A. F. Aspinall. President's Address. *Institution of Mechanical Engineers, Proceedings*, p. 474, 1909. *Also*, Train-resistance. *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 147, p. 166, 1901–2.

† *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 171, p. 282, 1907–8.

The calculated coal consumption in the case of steam traction is found to come below actual results owing to the effect of side winds and gradients; and to bring the figures into line with working conditions the coal consumption in the steam case, and the energy in the electric case, have been multiplied by the same factor. An example will show that this is justifiable. The train resistance for an express train is taken as 10 lb. per ton, which is the value on the level, while on an actual run with approximately the same weight of train the average draw-bar pull was nearly 17 lb. per ton. The figures taken agree very closely with those given in the "Locomotive Pocket Book," being 45, 60, and 55 lb. of coal per mile, as against the 40, 60, and 50 lb. respectively given in that pocket book for similar traffic. That the actual consumption is higher than this can be seen by taking Mr. O'Brien's figure * of £300,000 per annum for

TABLE 4.

Energy and Coal Consumption per Train-mile.

	Steam			Electric		
	Express	Goods	Suburban	Express	Goods	Suburban
Average speed ... ...m.p.h.	40	20	25	40	20	25
Resistance per ton of train ... ... lb.	10	9	9	10	9	9
Resistance per ton of loco ... ... ,,	15	12	14	11	8	
Average weight of train... ... ... tons	200	350	100	200	350	100
Average weight of loco ... ... ,,	67	70	40	50	50	25
Total resistance of train... ... ... lb.	2,000	3,150	900	2,000	3,150	1,125
Total resistance of loco ... ... ,,	1,000	840	560	550	400	
Kw.-hours per mile running	6·0	8·0	3·5	5·8	8·0	2·6
Miles per stop	20	10	1·5	20	10	1·5
Train braked from ... ...m.p.h.	35	15	35	35	15	30
Kw.-hours per stop	10·5	2·9	5·3	10·5	3·1	3·9
Kw.-hours per mile for stops	0·5	0·3	3·5	0·5	0·3	2·6
Calculated total kw.-hours per mile	6·5	8·5	7·0	6·3	8·3	5·1
Watt-hours per ton-mile (loco and train) ...	24	20	50	25	21	41
Coal per i.h.p.-hour ... ... lb.	3·0	3·0	5·5	—	—	—
Coal per kw.-hour ... ... ,,	4·0	4·0	7·4	2·35	2·35	2·35
Calculated total coal per train-mile ... ,,	26·2	33·2	46	15	19·5	12
Extra for getting up steam ... ... ,,	3·8	6·8	4	—	—	—
Factor to allow for gradients, wind, etc. ...	1·5	1·5	1·1	1·5	1·5	1·1
Coal per train-mile, taken as ... ... lb.	45	60	55	25·5	33	15·5
Coal per ton-mile (train only) ... ... ,,	0·225	0·17	0·55	0·127	0·095	0·155
Coal per ton-mile (train and loco) ... ,,	0·17	0·143	0·39	0·1	0·082	0·125
Average power, taken as ... ... kw.	390	250	192	378	250	142

TABLE 5.

Capital Costs (Electric).

One train per hour over each track.

	Express	Goods	Suburban
Average power per train at train ... ... kw.	380	250	145
Average power used per mile of track with 1 train per hour (effy. = 87 per cent) ... ... kw.	11·2	14·6	6·8
Ratio kw. installed / average kw. demand ... ... Sub-station	2·5	2·5	3
Ratio kw. installed / average kw. demand ... ... Power station	2·0	2·0	2·5
Kw. capacity installed per mile of track ... Sub-station	28	36·5	20·5
Kw. capacity installed per mile of track ... Power station	22	29	17
Cost of sub-station per mile of track at £5 per kw.	£140	£182	£102
Cost of power station per mile of track at £11 per kw. ...	£242	£321	£187
Interest and depreciation on power station and sub-station at 8 per cent	£30·5	£40·3	£23
Interest and depreciation per train-mile	0·84d.	1·1d.	0·65d.

* H. E. O'BRIEN. Electrification of railways. *Proceedings of the Manchester Association of Engineers,* Session 1911–12, p. 256.

the cost of the coal consumed on the Lancashire & Yorkshire Railway; if the cost per ton be 8s. 6d., this gives 90 lb. per locomotive-mile, assuming 12,300 miles per annum (the 1912 figure), as compared with 45, 60, and 55 lb. in the cases considered. Most of this difference will be due to the coal burnt in lighting up, in inefficient engines, and in engines held up by signals, etc., and would not occur in the electrical case. The figure on the London & North-Western Railway is over 100 lb. per locomotive-mile.

The amount of plant installed in the sub-stations and power station depends largely on the nature of the load. With main-line traffic the load would be much steadier than that experienced on the suburban lines at present electrified, where the rating of the plant installed is usually 2 or 3 times the average load. Table 5 shows the rating of the generating plant per mile of track, and it will be seen that the amount of plant is liberally estimated. In practice, accumulators would probably be installed and the amount of spare plant would be reduced, the annual charges for these batteries being more than balanced by the saving effected in the amount of plant required and in losses and repairs, to say nothing of the greater reliability of the supply.

Table 6 shows the values that have been assumed for the various items in the cost of generating the electrical energy. The coal cost appears low compared with most of the results that have been obtained, but it must be remembered that in the case considered the station would be equipped with the most up-to-date machinery, running on a very good load factor. That these figures are on a conservative basis can be seen by comparing them with figures published for Carville power station, viz. coal 0·0785d., engine-room wages 0·0223d., maintenance 0·016d.; giving a total of 0·1068d. per unit as against the 0·175d. assumed. Oil and stores have been purposely omitted in both the steam and the electrical cases, as the quantity used with the latter system at the generating station would be very small compared with that used by a large number of steam locomotives. It has been assumed that the cost of oil and stores for the electric locomotives and for the power station would equal that for steam locomotives.

The capital cost of the necessary electric locomotives has also been taken to be the same as that of steam locomotives, for although an electric locomotive is somewhat more costly, this is compensated by the extra mileage per annum which could be obtained, owing to the fact that it would not have to be idle for such a large proportion of the year for repairs and shed duties.

Table 7 gives a summary of the costs per train-mile for different types of traffic, and also the fixed annual charges due to electrifying one mile of track. From these two values it is possible to calculate the number of trains that must be run per hour in order that electrification may prove profitable. This will be seen to be 2·2 for express traffic, 1·9 for goods traffic, and 1·2 for suburban traffic. The necessary density of traffic on any railway would depend on the proportions of the various types of traffic. On lines with a large amount of suburban traffic it would approach 1·2 trains per hour, while on lines where through traffic predominates it would approach 1·9 trains per hour.

The number of trains per track-mile for the last half of 1912 varied from 1·2 to 1·8 for English railways, being in most cases nearer the latter figure. When it is remembered that on all railways a large proportion of the total length of track is installed on branch lines with sparse traffic, it will be seen that there is a considerable amount on which the critical density of traffic given in Table 7 would be exceeded, and would profitably stand electrification. Those sections of a railway where the traffic is least dense could be worked for a time by existing steam locomotives; and of course the whole of any railway could not be electrified at one time since the savings brought about by electrification would not be great enough to allow the wholesale scrapping of steam locomotives.

All the figures given are based on results which have been obtained in practice, the tendency having been to take the best steam figures and average electric figures so as to obtain a very safe estimate, which would probably

TABLE 6.

Cost of Electricity per Unit.

	Express	Goods	Suburban
	d.	d.	d.
Coal	0·085	0·085	0·085
Repairs (power station and sub-station)	0·05	0·105	0·06
Wages (power station)	0·04	0·04	0·05
Works cost at power station...	0·175	0·175	0·195
Interest and depreciation (sub-station and power station) ...	0·075	0·075	0·1
Sub-station wages per unit (with trains as below)	0·025	0·02	0·13
Feeders, interest and depreciation	0·03	0·025	0·1
Total cost per unit delivered to 3rd rail (effy. = 87 per cent) ...	0·35	0·35	0·605
Number of trains per hour to pay, approx. (see Table 7) ...	2	2	1·25
Number of units per hour per mile of track	22	28·6	8·2

be improved on in practice. Thus the running costs per mile for the second half of 1912 on the London & North-Western Railway were:

	Cost per train-mile
Wages connected with working of locomotive engines (excluding salaries, office expenses, and general superintendence)	4·35d.
Coal and coke	5·06d.
Water	0·17d.
Oil, tallow, and other stores	0·41d.
Total	9·99d.

would be materially reduced, the number of break-downs would be fewer, and compensation for firing crops, buildings, etc., would be eliminated.

In many cases in this country the lines are very congested, and electrification would be a profitable expenditure if undertaken only with the object of increasing the carrying capacity of these lines. Table 8 shows the amount of capital per mile of route for a few English railways; compared with these figures the cost of electrification is insignificant, so that even a small increase in the carrying capacity of a line would pay handsomely for the outlay on electrification.

TABLE 7.

Cost per Mile, Steam and Electric.

	Express		Goods		Suburban	
	Steam	Electric	Steam	Electric	Steam	Electric
A. Variable costs.	d.	d.	d.	d.	d.	d.
Repairs per train-mile	2·75	1·25	3·25	1·25	3·25	1·5
Coal per train-mile	2·42	1·07	3·2	1·4	2·95	0·67
Train crew (Running Dept.) per train-mile ...	Same		Same		2·0	1·3
Water per train-mile	0·2	—	0·2	—	0·15	—
Cleaners' wages per train-mile	0·5	0·25	0·5	0·25	0·5	0·1
Power station wages per train-mile	—	0·4	—	0·5	—	0·35
Power station and sub-station repairs per train-mile	—	0·45	—	0·7	—	0·42
Total variable costs	5·87	4·22	7·15	5·2	8·85	5·0
Saving per train-mile	—	1·65	—	1·95	—	3·85
Saving per annum per mile of track with one train per hour	—	£61	—	£72	—	£140
B. Fixed costs per annum per mile of track.		£		£		£
Track, interest, and depreciation (8 per cent) ...	—	72	—	72	—	80
Track repairs (electric)	—	20	—	20	—	20
Feeders, interest, and depreciation (8 per cent)	—	24	—	24	—	40
Sub-station wages	—	20	—	20	—	40
Total fixed costs	—	136	—	136	—	180
Number of trains per hour to pay	—	2·2	—	1·9	—	1·17
Figures above based on—						
Price per ton of coal	10s.	8s.	10s.	8s.	10s.	8s.
Power station wages per unit	—	0·04d.	—	0·04d.	—	0·05d.
Repairs per unit	—	0·05d.	—	0·05d.	—	0·06d.
Miles between sub-stations	—	15	—	15	—	7·5
Cost of track equipment per mile	—	£900	—	£900	—	£1,000
Number of units per train-mile	—	9·5	—	12·5	—	5·7

These are all considerably above the values taken in Table 7.

No account has been taken of many other savings which would result from electrification, but to which it is difficult to fix a monetary value. The coal at present burnt on locomotives held up by signals, waiting to shunt, etc., amounting to about 150 lb. per locomotive per hour, represents a considerable sum which could be saved. The painting and cleaning bill for both stations and carriages

POSSIBILITIES OF FUTURE IMPROVEMENTS.

Coal consumption.—In Table 9 is shown the efficiency of a perfect steam engine under different conditions.

(1) Common locomotive practice.
(2) Common steam-turbine practice.
(3) Increased superheat.
(4) Increased boiler pressure.
(5) Steam re-heated after falling to saturation point.

(2) to (5) indicate that no great increase in the possible efficiency can be obtained without very radical changes in the conditions of working. When it is remembered that some modern turbines work to within 68 per cent of the efficiency possible with a perfect engine under the same conditions, it can be seen that there is little prospect of the amount of coal per unit being very much reduced.

The gas engine has no such limits to its efficiency, and already the latter exceeds that of the steam engine. The results obtained at Accrington * show an overall efficiency of 17·5 per cent against 15 per cent for very good steam plant. In addition to being more efficient, a gas plant produces valuable by-products, for which there is a practically unlimited demand. Thus, according to the published results obtained with the Accrington plant, the following figures per unit are readily obtained: Coal 0·08d., sale of ammonium sulphate 0·133d., sale of tar 0·016d. From this it will be seen that the sale of by-products yields about 1¾ times the cost of coal. This is of course not all clear profit, since the recovery of the by-products involves extra expenditure in acid, labour, and capital charges; about one ton of acid is required to produce one ton of ammonium sulphate, so that at the present prices, £2 2s. per ton and £12 per ton respectively, the acid costs only about one-sixth the price obtained for the sulphate. The extra capital charges and labour will vary in each case according to the size of the plant, the load factor, and other conditions, but in no normal conditions will they represent anything like the price obtained for the by-products.

* *Science Abstracts*, vol. 16, B, No. 1031, 1913.

The efficiency of a gas engine does not increase to any extent after a moderate size has been reached, so that there appears to be a future for gas engine plants located at intervals along the line, instead of a central station with sub-stations. This would eliminate sub-stations and feeder costs and the capital cost would work out at about £19 per kilowatt, or at about the same rate as steam plant with sub-stations. There would also be less liability of a complete shut-down.

It is also possible that the locomotive running wages might be considerably reduced by electrification. These amount to 4·35d. per locomotive-mile on the London & North-Western Railway, so that if a second man on the engine could be dispensed with, as would appear possible on a considerable number of trains, a reduction in the running costs of 1d. to 2d. per train-mile would result. This would render electrification profitable with only about one train per hour along each track. The double heading of trains without increasing the train crew would still further reduce the running wages.

One of the reasons for the slow progress of electric traction is probably the uncertainty as to which is the best system. Railway directors cannot be expected to sanction large schemes when electrical engineers, both railway and manufacturing, are wrangling as to which is the best system. It would appear that when a little more experience has been obtained with high-tension continuous current, a round-table conference of manufacturing and railway engineers would serve a useful purpose. Such a gathering should be able to settle which system is the best for the average conditions of this country.

TABLE 8.

Railway Capital per Mile of Route (1912).

Railway	Great Western	Lancashire & Yorkshire	London & North-Western	Great Eastern	Midland	North London	Liverpool Overhead	London Electric	Metropolitan
Capital per mile	£33,000	£117,000	£63,500	£45,000	£129,000	£255,000	£132,000	£784,000	£675,000

TABLE 9.

Efficiency of Perfect Steam Engine under Various Conditions.

		Steam Loco	Average Turbine Practice	Higher Superheat	Higher Boiler Pressure	Re-superheat
Boiler pressure absolute ...	lb. per sq. in.	195	200	200	300	200
Superheat	° F.	100	200	400	200	200 and 300
Exhaust pressure	lb.	15	0·5	0·5	0·5	0·5
Feed water temperature	° F.	60	80	80	80	80
Heat utilized per lb. of steam ...	B.Th.U.	200	404	460	437	460
Heat supplied per lb. of steam ...	,,	1,170	1,246	1,342	1,257	1,399
Efficiency of perfect engine		17·0 %	32·5 %	34·3 %	34·8 %	33·1 %
Steam per i.h.p.-hour	lb.	12·8	6·28	5·53	5·8	5·5

THE LAWS OF DIELECTRICS.

By W. S. Flight, Student.

(*Abstract of Paper read before the* Manchester Students' Section *25th November*, 1913.)

General.

The study of dielectrics is the exact counterpart in electrical engineering to the study of the strength of materials in mechanical engineering, but on account of the great difficulties met with in the study of electrical stresses and strains, our knowledge of the latter is by no means as complete as our knowledge of the former. An attempt is made in this paper to set forth many of the fundamental laws which have been deduced from numerous test results, and references are made to a few points which the author has had an opportunity of investigating. Dielectrics will be considered under three main classes, since the effect of an electrical stress under stated conditions differs for different dielectrics.

I. Gaseous Dielectrics.

When a layer of air at ordinary atmospheric pressure and temperature is subjected to an electrical stress which is gradually increased until the air breaks down, three distinct discharges are observed. As soon as the voltage has reached a certain value a faint glow appears on the electrodes, and the discharge is known as the "glow" discharge. As the voltage is steadily raised, this glow gives place to the "brush" discharge, and at a still higher voltage the brush discharge passes into the arc.

Liquid and solid dielectrics do not show these three discharges in so marked a degree, even under the most favourable circumstances, so that in order to compare the properties of all dielectrics the ultimate breakdown value is adopted and all the figures quoted in this paper refer to this third discharge.

The breakdown voltage of any layer of air is influenced by many factors, of which the following are some of the most important.

(1) *Method of application of the voltage.*—The following are the principal ways in which voltage may be applied to a dielectric: (*a*) In the form of a regularly increasing voltage; (*b*) by even steps large or small, the circuit always remaining unbroken; (*c*) by a sudden application.

The effect upon the breakdown voltage of a definite thickness of air only varies slightly unless the circuit contains capacity and inductance (which may cause surges when the voltage is applied by suddenly closing a switch on either the high-tension or low-tension side). The reason for this may be attributed to the fact that air has practically no time factor until a corona appears, and it can easily dissipate any heat produced.

(2) *Electrostatic fields produced by surrounding objects.*—This has only been extensively studied in the case where one terminal of a testing transformer becomes earthed, when a reduction in the breakdown voltage as shown in Fig. 1 occurs. Its amount varies with the setting of the gap, the applied voltage, and the shape of the electrode. The effect of the latter with spheres of different sizes is shown in Table 1. In Fig. 1, where the electrodes consist of spheres of 12·5 cm. diameter, the earthing had practically no effect up to 100 kilovolts; if, however, a needle gap be used, the curves have been found to diverge at about 30 kilovolts.

The electrodes in these tests were separated by at least three times the gap distance from all surrounding objects; although no figures are available for tests at other distances, it is probable that the electrostatic field is considerably changed at shorter distances and the breakdown voltages further reduced.

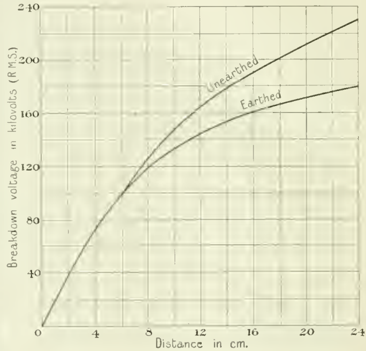


Fig. 1.

(3) *Shape of electrodes.*—The shape of the electrodes employed has a considerable influence. In Table 1 the breakdown voltage of the constant gap of 25 cm. and with both terminals unearthed varies from 230 kilovolts for spheres of 12·5 cm. diameter to 400 kilovolts for 50 cm. spheres.

Table 1.

Decrease in Breakdown Voltage for a Constant Gap Setting of 25 cm.

Diameter of Spheres	Breakdown Voltage. Unearthed	Breakdown Voltage. Earthed	Percentage Decrease in Breakdown Voltage
Cm.	Kilovolts (R.M.S.)	Kilovolts (R.M.S.)	
12·5	230	180	21
25	310	280	9·7
50	400	375	6·2

Fig. 2 shows the results of another series of tests made between electrodes of the shape shown. Here it will be

observed that the curve between point and plane is much lower than the point-to-point curve, whilst the curves for circular plates to points are lower still.

For gases and liquids the order of electrodes placed in a descending scale is roughly as follows :—

Parallel plates of infinite area.
Spheres of large diameter.
Spheres of smaller and smaller diameter.
Point to point.
Point to plain.

The cause of the vast difference observed in the breakdown voltage with differently shaped electrodes is to be

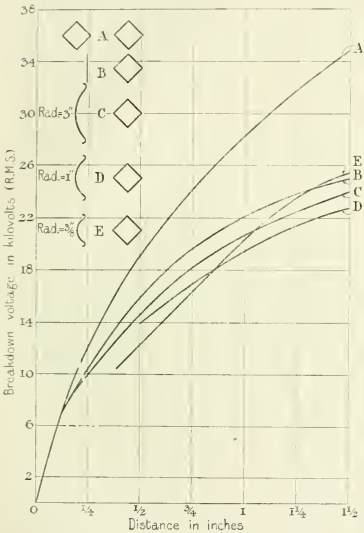


FIG. 2.

found in a study of the flux distribution on the electrodes. Some interesting diagrams which the author obtained by sticking flat tin-foil electrodes to an unexposed photographic plate and causing a brush discharge to pass between them in a dark room, have shown that the electrons and atoms are shot off approximately at right angles to the surface of the electrodes, and that the amount of concentration possible in these electric fields is far greater than in magnetic fields, so that the latter cannot always be taken as a true indication of the conditions existing under an electric stress. This non-uniformity of the electric field increases as the voltage between the electrodes increases. Thus at fairly low voltages the effect of the shape of the electrode is not very marked; its influence, however, becomes of far greater importance at higher voltages.

(4) *Character of the circuit.*—(a) *Frequency.* Over the range of commercial frequencies (25–100 ∿) there has been found to be practically no variation in the breakdown voltage. At telephonic frequencies a slight decrease has been observed with increase in frequency.

(b) *Wave-form.* Since the strength of a dielectric is dependent on the maximum voltage and not on the R.M.S. voltage, peaked waves produce breakdown at a lower voltage than a sine wave.

In comparing tests on air with both alternating and continuous currents it is found that the continuous-current breakdowns are approximately $\sqrt{2}$ times the alternating-current values.

(5) *External ionization.*—Since electrical conduction consists of definite motion of free electrons, and dielectrics are materials which naturally contain very few free electrons, it follows that a breakdown does not take place until electrons are liberated. This liberation of electrons may take place in two ways :—

(a) By placing the dielectric between two plates maintained at different potentials. The atoms will then tend to fly towards the negative plate and the electrons to the positive, so that as soon as the electrical field is strong enough to overcome the atomic attraction electrons will be liberated and a current will pass. (b) When a radioactive particle passes through the atoms of a dielectric it liberates a number of the electrons by displacing them in their orbit round the atom—a phenomenon known as ionization by impact. Ultra-violet rays and sunlight possess in a less degree this power of causing ionization by impact. During some experiments conducted by Dr. W. Weicker in Germany it was found that the ultra-violet rays produced by two arc lamps lowered the voltage of a glow discharge by 4 per cent. No effect was in this case found on the breakdown voltage, probably because the experiments were conducted with needle points or spheres of small diameter, in which case ionization would be already present as the result of the brush discharge.

(6) *Thickness of test piece.*—The breakdown voltage of a dielectric per mil always decreases with increase in thickness but not proportionally therewith. The various formulæ put forward from time to time show so much disagreement that the subject requires further investigation. The reason for this decrease is not perfectly clear, but since it is a common property of all dielectrics it seems probable that it is due rather to a change in the electric field produced by increasing the distance between the electrodes than to any property of the dielectric, such as the heating of certain layers or the heterogeneity of the material. On account of this decrease in voltage with thickness, the practice of comparing various insulating materials by comparing the breakdown voltages per mil is not to be recommended unless the thickness of all the test pieces is approximately the same and the tests have been carried out between electrodes of the same size and shape.

(7) *Mechanical pressure.*—This is another special study in dielectrics which has not as yet been very fully investigated. In the case of air, however, it is known that the breakdown voltage is very susceptible to mechanical

pressure, both the voltage of glow discharge and the breakdown voltage increasing as the density of the air is increased, the law in each case being expressible by a linear equation.

(8) *Temperature.*—The law, which is approximately true over a fairly large range of temperature, is that the voltage is inversely proportional to the absolute temperature. The voltage of glow discharge has been found to obey this law more closely than the breakdown voltage; in the case of the latter it would appear that the voltage decreases rather more rapidly than it would if it followed the law of inverse ratio to the absolute temperature.

(9) *Moisture.*—The quantity of moisture present in a dielectric has a very large influence on the breakdown voltage. From a commercial point of view its effect is perhaps more important than that of any of the other disturbing influences considered, and when dealing with liquids and solids its effect will be considered in detail. In the case of air the voltage of glow discharge is unaffected by the amount of moisture present, but the growth of the brush discharge is greatly hindered by an increase in the humidity; consequently when using needle points or small spheres the breakdown voltage is also raised. The increase with needle points amounts to as much as 17 per cent for a variation in the percentage humidity from 0 to 80 per cent.

(10) *Time of application of voltage.*—When voltage is suddenly applied to liquid and solid dielectrics it is found that the breakdown voltage is considerably higher than that obtained on the same material when a time test is given. With air except at very high voltages there is practically no difference in the two results.

II. Liquid Dielectrics.

Speaking generally the remarks made in sections (1) to (6) under "Gaseous Dielectrics" apply equally to oils. The remaining sections, however, require to be considered separately.

(7) *Mechanical pressure.*—Since liquids are incompressible compared with gases, the effect of compression upon their breakdown voltage is negligible.

(8) *Temperature.*—The dielectric strength of air and of all solid dielectrics decreases with increasing temperature; in the case of oil, however, the effect is reversed, the breakdown voltage increasing with the increase in the temperature of the oil. Messrs. Digby and Mellis in their paper* drew attention to this property of oils and showed a number of interesting curves obtained by slowly warming a sample of oil in an apparatus in which the breakdown voltage could be ascertained from time to time at definite temperature intervals. Some of these curves are approximately linear, and some are not, the tendency being for the curves to bend upwards at the higher temperatures. This can be accounted for by the superposition of the increase due to the drying of the oil (since apparently the oils were not subjected to any previous drying) upon the increase due to increase in temperature. In some experiments carried out by the author on samples of oil which had been previously well dried in an oven, it was found that the law of increase in breakdown voltage with increase in temperature is a linear one as shown in Fig. 3. Further, it was found that the gradient of the curves was approximately the same for two samples of transformer oil having about the following specific gravities: A = 0·82, B = 0·86, and amounted to approximately 0·47 per cent per degree Centigrade rise of temperature. This percentage increase is calculated on the breakdown voltage at the ordinary air temperature (say 20° C.) and holds good for all temperatures up to 130° C.

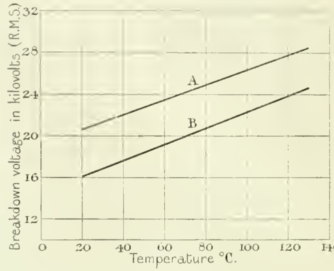


Fig. 3.—Transformer Oils.

A = Mineral oil, specific gravity 0·82 at 20° C., flash-point 130° C.
B = ,, ,, ,, 0·86 ,, ,, ,, 165° C.

(9) *Moisture.*—Probably in no other dielectric is the detrimental effect of moisture so clearly shown as it is in the case of oils, the presence of 0·02 per cent of water reducing the breakdown voltage by nearly 70 per cent of that of perfectly dry oil.

In the commercial handling of large quantities of oil for insulating work, this drying of the oil presents many

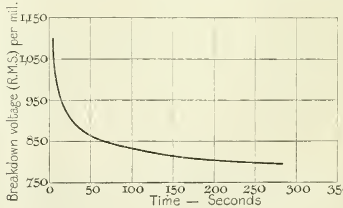


Fig. 4.

difficulties, for the last traces of moisture are by no means easily removable, and heating the oil for any length of time at temperatures above 120° C. in contact with air is liable to cause damage to the oil by chemical changes. Vacuum heating is the ideal system, but it is costly and often impossible to carry out. An ingenious method of drying the oil without the application of heat consists in filtering the oil through a number of filters made of a material similar to the ordinary filter paper. The affinity

* W. P. Digby and D. B. Mellis. The physical properties of switch and transformer oil. *Journal I.E.E.*, vol. 45, p. 165, 1910.

of water for oil being much less than that of water for water, it is found possible by this means to carry the drying to a very high point on the curve, not only in a laboratory test but also in practice.

(10) *Time of application of voltage.*—Fig. 4 is a typical time-voltage curve for oils. It will be noticed that after about 200 seconds the curve becomes parallel to the time axis. This time (200 seconds) is known as the "time factor" of the dielectric. It varies from about 1 minute to 15 minutes for most insulating materials, and it also depends to some extent upon the amount of moisture present in the sample under test.

(11) *Presence of foreign matter in the oil.*—(*a*) In switch work due to the breaking of the arc under oil a large number of carbon particles are formed. Due to the electrostatic field these particles will, under certain conditions, line themselves up so as to produce a breakdown at a very much lower value than is required to break down the oil when clear, as shown in Table 2.

TABLE 2.

Name of Oil	Breakdown Voltage of Clear Oil	Breakdown Voltage of Oil Containing Carbon Deposit	Per Cent Decrease in Breakdown Voltage
A	22,000	16,000	27
B	14,200	9,000	36

One of the most interesting points about this "lining up" is the time element involved. The action is by no means instantaneous and the time of duration varies with the quantity of carbon, the shape of the electrodes, the voltage between them, and the viscosity of the oil.

(*b*) In transformer work another form of deposit is met with, which is precipitated as the result of certain chemical changes that take place in the oil due to oxidation. The presence of this sludge in oils, however, was found to reduce the breakdown voltage by only 5 per cent, and it is not as detrimental as the carbon deposit.

III. SOLID DIELECTRICS.

Solid dielectrics used in practice are as numerous as the liquids and gases are few. Roughly they may be divided into two main groups :—(*a*) organic, (*b*) inorganic ; and in considering the dielectric properties of solids both of these groups may in many cases be treated together. Roughly speaking, sections (1) to (6), with the exception of section (3), in the first part of this paper apply equally to solids.

(3) *Shape of electrodes.*—It was pointed out in the first part of this paper that in the case of gases and liquids the breakdown voltage decreased as the radius of the electrodes was decreased. In the case of solid dielectrics the reverse is, however, found to be true. Thus we have a rather remarkable state of affairs, for in order to determine the minimum value of the dielectric strength of gases and liquids, points, or better still a point and a plane, should be used ; whilst for solids, on the other hand, flat plates are the correct electrodes to use in order to determine this minimum value. The cause of this difference seems to lie in the fact that gases and liquids being physically homogeneous bodies the breakdown voltage is independent of the area under stress, whilst solids being far less homogeneous will be influenced by the area under stress.

(7) *Mechanical pressure.*—Here again the subject does not appear to have been scientifically studied, and the results of what few experiments the author has been able to make tend to show that with most fibrous materials the breakdown voltage decreases with increase in the mechanical pressure. The decrease was small within the range of pressures applied, viz. up to about 80 lb. per square inch.

(8) *Temperature.*—The breakdown voltage of all solid dielectrics decreases with temperature, although moderate rises of temperature have little effect as a rule upon inorganic materials. Fig. 5 shows the decrease in the

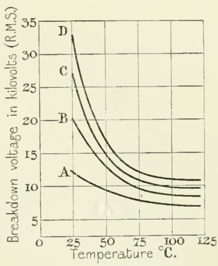


FIG. 5.—Empire Cloth.

A = 1 layer. C = 3 layers.
B = 2 ,, D = 4 ,,

case of empire cloth. These tests were done by immersing the material in oil, which had previously been heated to the required temperature, and obtaining the breakdown before any drying of the material could take place. When fibrous materials containing a large percentage of water are slowly heated at moderate temperatures some of the water is driven off and the dielectric strength is in consequence increased. This effect, however, is really due to moisture, and when tests are carried out on dried samples of the same material at the same temperature there is always found to be a decrease in breakdown voltage with increase in temperature.

(9) *Moisture.*—All organic materials contain a certain percentage of moisture, and unfortunately they are all capable of absorbing an excess of moisture from the air in such a way as to cause a serious decrease in their dielectric strength. Papers, for example, usually contain from 5 to 15 per cent of moisture, and in order to preserve the mechanical properties of the paper it is essential that the majority of this natural moisture should remain. The problem thus consists in drying off all excess moisture and in treating the material by means of varnishes, oils, or compounds, so as to prevent a re-absorption of any excess moisture.

(10) *Time of application of voltage.*—All solid dielectrics possess a considerable time factor, and there appears to be a marked similarity between the time-voltage curves of different solids. Fig. 6 is a typical curve for a stator coil insulated with empire cloth and mica. When a number of thicknesses of the same material are tested together it is found that the time factor increases as the number of layers is increased.

(11) *Testing solid materials in air or oil.*—Very often in commercial insulation testing it is found impossible to

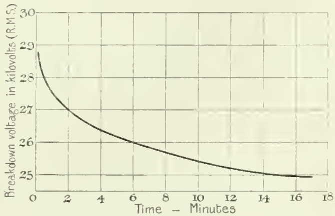


FIG. 6.—Stator Coils Insulated with Empire Cloth and Mica.

obtain an ordinary breakdown test on a particular sample owing to the flash-over voltage being less than the puncture voltage. The usual practice is then to immerse the sample and electrodes under oil, thereby increasing the flash-over voltage four or five times and rendering a puncture test possible. Placing the material in a medium having a specific inductive capacity more nearly equal to its own, however, is bound to alter the distribution of the electrostatic field, and in consequence a different breakdown voltage may thus be obtained. This is impossible to calculate, but when using electrodes of flat discs with rounded edges it has seldom been found in practice to vary more than 5 per cent from the breakdown voltage obtained in air.

Tests under oil have a peculiar effect upon certain dielectrics. Former experimenters have remarked on the decrease in the breakdown voltage obtained when testing mica under oil, compared with that obtained in air. The author has noticed this in the case of built-up mica and also in the case of celluloid. It is never experienced in fibrous materials and appears to be due to the imprisonment of a thin film of oil between the electrodes and the dielectric.

(12) *Flash-over voltage.*—In all solid dielectrics there is a path across the surface of the material alternative to the

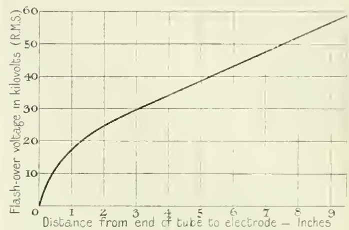


FIG. 7.—Mica Tube.

path through the material. In certain insulation designs this flash-over voltage becomes a more serious factor than the actual puncture voltage, and the question has been studied to some extent, but no very definite laws have been deduced. Fig. 7 shows the flash-over voltage across a mica tube, and it is interesting to note that after a certain point the curve is a linear one, which property seems common to most flash-over curves across a clean surface. When the surface is dirty or dusty the flash-over voltage is enormously reduced. It varies considerably with the material of which the surface is composed, and is very susceptible to a rough or smooth surface, the presence of irregularities on the surface of fibrous materials causing a decrease in the flash-over voltage.

THE CONTROL OF ELECTRICAL GENERATORS BY AUTOMATIC PRESSURE REGULATORS.

By E. L. M. Emtage and A. Arnold, Students.

(*Abstract of Paper read before the* Students' Section *1st April*, 1914.)

Automatic pressure regulators for the control of electrical generators may be roughly classified as :—

(*a*) Rheostat type,
(*b*) Vibrating-contact type.

These names have been chosen as covering the various types of regulators discussed in this paper, although regulators which fall under either of these headings may differ widely in their constructional details.

By the "rheostat type" is meant all those regulators which act by adding or cutting out more or less of a variable resistance in the field circuit of the machine which is automatically controlled. This operation may be performed in one step or gradually, and class (*a*) may therefore be subdivided into :—

(1) Regulators in which the rheostat is directly controlled by a motor operated by the fluctuation of the line pressure.
(2) Regulators in which the rheostat is adjusted by means of a relay (electrical or mechanical) controlled by apparatus actuated by the fluctuation of the line pressure.

By the "vibrating-contact type" is meant all those regulators in which a vibrating or oscillating member short-circuits and puts into circuit a device for altering the excitation of the generator or exciter. This type includes :—

(1) Regulators in which there is intermittent short-circuiting of the whole or part of a field resistance by means of vibrating contacts which are controlled by suitable apparatus actuated by the line pressure.

(2) Regulators in which an oscillating member alternately short-circuits the two opposing components of a booster field, thereby causing an electromotive force to be introduced into the generator or exciter field-circuit.

Under these headings the paper deals with the following regulators :—

Rheostat type.—Thury, Routin, and Brown Boveri automatic pressure regulators.
Vibrating-contact type.—Tirrill, British Westinghouse (Olmsted), Oerlikon (Fuss), Siemens Schuckert, and Taylor Scotson automatic pressure regulators.

At first sight it would appear that the advantages are all on the side of the vibrating-contact systems, but troubles originating from sparking at contacts—when they do occur—cause greater inconvenience than is possible with the rheostat type, owing to the regulator raising or lowering the excitation to a greater extent than it is possible for the rheostat type of regulator to do. Sparking with the rheostat type is less frequently met with, and in the event of failure this type of regulator merely cuts itself out of circuit, leaving the pressure nearer to the normal than the vibrating-contact type would do. Contact troubles with the vibrating-contact type are easily avoided by cleaning the contact points from time to time.

Stability.

The regulation of a given generator depends upon its magnetization characteristic, which is usually of the shape shown in Fig. 1.

The best results in automatic pressure regulation are obtained when working on the middle portion of the characteristic, just on or above the "knee" (from A to B in Fig. 1). This portion of the curve gives a proportionate

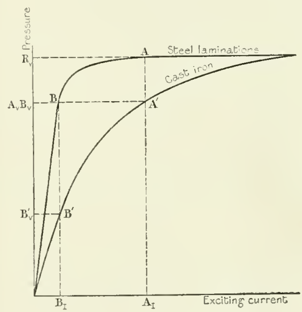


Fig. 1.

increase in pressure for a given change of the excitation, whereas in the flatter portions of the curve, beyond the saturation point, a large variation of the exciting current gives but a small increase in the generator pressure, with the result that regulation would be slow and the currents with which the regulator has to deal would be unnecessarily large.

Below the knee of the magnetization characteristic the regulation is much more rapid, but if the curve is at all steep, as with a laminated steel field (see Fig. 1), there is a tendency to instability with self-excited machines, which is more particularly noticeable with the rheostat type of regulator.

For a given generator or exciter pressure V the exciting current is I and the resistance in the field circuit is R, this giving stable working. Supposing now that, due to a change in load, V becomes increased to V′ then the equation $V = I\ R$ becomes $V' = I'(R + r)$, where r is the resistance inserted by the automatic pressure regulator. This

equation may not give stability, for the current I′ may not give sufficient excitation to maintain the pressure at V′, and V′ may not be a sufficient terminal pressure to maintain the excitation, so that the effect becomes accumulative and the pressure falls away. The automatic regulator will cut its resistance out of circuit with this fall in pressure, the field resistance again becoming R, but the values V and I are not obtained at once as the field must be built up; due to the inertia of the field there will be an overshooting effect so that V will be momentarily exceeded, when the automatic regulator will again insert resistance reducing both the exciting current and the terminal pressure. The cycle of operations will thus be repeated, with the result that there will be continuous surging, the extent of which will depend upon the rapidity of action of the regulator. The vibrating-contact type of regulator, however, operates so rapidly that surging is not usually obtained.

For the rheostat type of regulator a curve with a gradual slope and a "knee" spread over a considerable portion of the curve—such as is obtained with a cast-iron field system—gives the better regulation, since a given change in excitation will give a proportionate change in terminal pressure, and not too large a change such as would be obtained with a steeper characteristic curve.

In installing a regulator of the rheostat type to operate in conjunction with an exciter which has a steep magnetization characteristic, or which is working on the steeper portion of its magnetization characteristic, it is often an advantage to introduce a fixed rheostat into the generator field circuit, so as to cause the exciter to work on a higher and less steep part of its characteristic. A further advantage obtained by the insertion of the main field rheostat is discussed under "Speed of Regulation."

In the case of vibrating-contact regulators the shape of the magnetization characteristic is of less importance, as the regulators can compensate for the steepness or shape of the curve by dwelling rather longer in one position of each oscillation.

Automatic Regulator Characteristics.

There are two main regulator characteristics, the "static," in which each position of the regulator corresponds to a definite pressure, and the "astatic," in which any position of the regulator corresponds to a constant pressure.

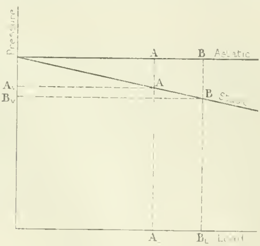


Fig. 2.

The static characteristic is a falling characteristic owing to an increase in the action of the controlling force of the regulator as the load increases not being accompanied by a corresponding increase in the operating force (the pressure coil). This characteristic is admirably adapted for use with generators operating in parallel, since no generator can take more than its fair share of the load without a corresponding decrease in pressure due to the falling characteristic (see Fig. 2).

The astatic characteristic is a level characteristic giving a steady pressure from no-load to full load, and it is obtained either by adjusting the controlling force so that it is constant at all loads, or by introducing a current element into the operating force, thereby causing an increase in the effect of the regulator with an increase in the load. This type of characteristic is unsuited for parallel operation (except in one instance), since one generator may take all the load without any action of the regulator, unless the latter is provided with a current element.

Trailing.

By the term "trailing" is understood the regulation of a generator by means of circulating currents from an automatically regulated generator with which it is operating in parallel; that is to say, for changes in load and pressure the excitation of the automatically regulated generators is altered but that of the trailing generators remains fixed, and they are regulated by armature reaction by means of circulating currents from the regulated generators. If there is any difference in size it is usual to arrange for automatic regulation on the generators having the largest outputs. This system gives excellent results but is not so convenient, quick, or accurate, as the separate regulation of each generator.

Speed of Regulation.

The accuracy of a given automatic pressure regulator depends almost entirely upon the speed of regulation. The latter depends not only upon the regulator itself but also very largely upon the design of the generator and of the exciter. A fall in pressure calls for an increase in excitation, and the time taken to effect this depends upon the "time constant" of the magnetic circuit. In the case of generators with exciters the excitation of both the generator and the exciter having to change takes a correspondingly longer time. In the case of the generator there is no final change in flux, the extra excitation being required to overcome armature reaction. The flux of the exciter, however, has also to change; this takes a longer time, and so the chances of pressure variation are greater than with a self-excited generator.

The "time constant" of a field circuit being proportional to the self-induction divided by the ohmic resistance of the circuit, it can evidently be reduced by increasing the ohmic resistance, and this is often done in the case of old-pattern machines by means of inserting ohmic resistance in the field circuits so as to increase the speed of regulation.

The speed of the vibrating-contact type of regulators is usually somewhat greater than that of the rheostat type of regulator, but in practice an accuracy of $\pm$ 1 per cent to $\pm$ 0·25 per cent is obtained with either type, this accuracy being sufficient for all practical purposes.

The principle of "overshooting," or allowing the regulator to add or cut out more resistance than is necessary to obtain correct pressure, so as to overcome the inertia of the field circuits, is one of the essential principles of the Tirrill type of regulator, but it has been employed in various other types of regulator and is successfully used with the rheostat type.

Automatic Regulation of Continuous-current Generators.

Continuous-current generators may be classified as separately excited generators, and self-excited generators. The former type may be excited, either by an entirely separate source—in which case the regulator would act directly on the field circuit—or by means of an exciter, when it is usual for the regulator to operate on the exciter field circuit, the energy to be dealt with in that case being considerably less.

In the case of self-excited generators, whether of the shunt or compound type, the regulator must necessarily act directly on the generator field circuit. In each case, whether separately or self-excited, shunt or compound wound, it will be noticed that the generator characteristics tend to droop over on the higher loads owing to the saturation of the iron and the predominance of armature reaction. This is also true of over-compounded generators, and although certain machines are said to be "level compounded" this merely signifies that the terminal pressure at full load is the same as that at no-load.

The effect of a purely pressure regulator with a static characteristic is to straighten out the characteristic curves of the generators, raising the drooping portions and levelling the upward curves of the compounded machines.

By using an astatic or compounded regulator the generator characteristics can be so altered as to obtain level compounding with a shunt-wound generator, or over-compounding if required, which is a great advantage inasmuch as it abolishes the necessity for a compound winding on the generator.

Automatic Regulation of Continuous-current Generators in Parallel.

The automatic regulation of two or more continuous-current generators can be effected in either of two ways: each generator may have a separate regulator which is arranged with a "static" characteristic, or else one astatic regulator may control all the generators. The latter arrangement will only be possible with generators having exactly similar characteristics to avoid the circulation of currents between the generators and the demagnetization of one of them.

Trailing as a means of automatic regulation may be satisfactorily adopted with continuous-current generators operating in parallel, but in this case also the generators have to be similar in order to prevent demagnetization.

The advantage of controlling each generator separately is that the characteristics of the generators can be so altered by adjustment of their individual regulators that they will share the load equally at all loads and at constant pressure. In this case if there is no compounding arrangement the regulators should have static characteristics, so that the falling characteristics will tend to keep the load evenly distributed among the generators by alteration of the excitation with change of load. In the case of separately excited generators operating in parallel and controlled by the same regulator, the exciters must be connected in parallel in order to ensure uniform excitation of the generators. If the excitation is not uniform then one generator may take the bulk of the load, possibly also demagnetizing the other generators.

An interesting application of the continuous-current compounding regulator is seen in the case of the automatic regulation of traction generators in parallel. In place of the usual compound-wound generators with equalizing connections, shunt-wound generators compounded by means of compounding regulators can be used, a separate regulator being provided for each generator and a current shunt being substituted for the compound winding of each generator. It will be seen from this that a single current shunt placed in the busbars and connected to each of the regulator compounding coils will give the same effect—an arrangement which is cheaper and more simple than that of using compound-wound generators and equalizing connections.

Automatic Regulation of Alternators.

The automatic regulation of alternating-current generators is essentially the same in practice as that of

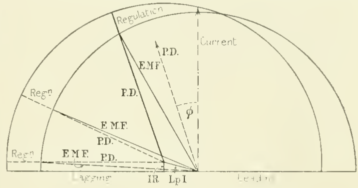


Fig. 3.

continuous-current generators, the pressure of the alternator depending upon the balance between the magnetic effect of the field and that of the armature reaction. When this balance is upset in either direction, the excitation is altered accordingly until balance is restored.

There is, however, a question of power factor to be taken into account. From a consideration of the vector diagram shown in Fig. 3 it will be seen that the amount of the regulation of an alternator depends upon the power factor at which it is working. The current is set off vectorially, and against it is plotted a vector at an angle ϕ, the cosine of which represents the power factor at which the alternator is working; this will represent the direction of the terminal potential difference of the alternator. The LpI, I R, and E.M.F. vectors are set off in the usual manner and the P.D. vector will be drawn at an angle ϕ to the vertical. The difference between the P.D. and E.M.F. vectors will give the regulation pressure-drop of the alternators, and by drawing circles having their radii equal to the E.M.F. from the lower ends of the E.M.F. and P.D. vectors respectively, the regulation pressure-drop of the alternator at any power factor will be represented by the distance between the circumferences of these circles.

From the diagram (Fig. 3) it can be seen that the

potential difference is least when $\phi = 90°$, and that the regulation will then be greatest; also that with a leading power factor the potential difference may exceed the E.M.F. and the regulation will be a negative quantity. This is due to the magnetizing effect of the armature reaction.

With single alternators separately controlled and working alone it is possible to regulate the pressure, but the power factor must vary with the load. With this arrangement the automatic variation of the excitation alone brings about variations of a power factor, for an increase in the excitation cannot increase the output of the alternator, this being dependent upon the mechanical power supplied to the generator.

When alternators are operating in parallel the question of the variation of power factor with automatic variations of the excitation becomes more serious and the distribution of the synchronizing and circulating currents between the generators has to be taken into account.

The following case will serve to illustrate the variation of the power factor with a variation of the excitation :—

An alternator operating in parallel with several others is automatically regulated. The potential difference at the

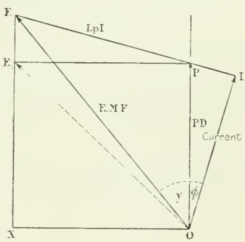


FIG. 4.

terminals will be practically constant, as will also be the mechanical power supplied by the prime-mover. The armature resistance being so small can be neglected, so that the power taken from the prime-movers and converted into electrical power

$$= \frac{\text{E.M.F.} \times \text{terminal P.D.}}{\text{Self-induction of the armature}} \times \text{Sine of the angle between E.M.F. and P.D. vectors.}$$

In Fig. 4 the terminal P.D. is shown lagging by an angle γ behind the vector of the E.M.F. generated and in advance of the current by an angle ϕ.

Let O P = terminal P.D. vector,
O E = vector of E.M.F. generated,
P = power taken from the prime mover and converted into electrical power,
Lp = armature self-induction,
$Lp\,I$ = E.M.F. of armature self-induction.

Now $$P = \frac{\text{E.M.F.} \times \text{P.D.}}{Lp} \times \sin \gamma,$$

$$\therefore P \times Lp = \text{E.M.F.} \times \text{P.D.} \times \sin \gamma.$$

Since P and the P.D. are constant, and the triangle O P E = P.D. × E.M.F. × $\sin \gamma = P \times Lp$, ∴ the triangle O P E must have a constant area.

The result of this is that as the E.M.F. is varied by automatic adjustment of the excitation, the point E (Fig. 4) will move up and down a line E X parallel to the P.D. vector O P, which is the base of the triangle O P E.

Now $PE = Lp\,I$ = the inductive drop in the armature 90° out of phase with the current. If the excitation be decreased till $OE = OE_1$, the inductive drop $Lp\,I$ will have a minimum value PE_1.

And since $\sin \gamma$ now $= \frac{PE_1}{\text{E.M.F.}}$, by substituting in the equation—

$$P = \frac{\text{P.D.} \times \text{E.M.F.}}{Lp} \times \sin \gamma,$$

one obtains $$P = \frac{\text{P.D.} \times \text{E.M.F.}}{Lp} \times \frac{PE_1}{OE_1},$$

$$= \frac{\text{P.D.} \times \text{E.M.F.} \times Lp\,I}{Lp \times \text{E.M.F.}},$$

$$= I \times \text{P.D.}$$

That is to say the power taken from the prime-mover and converted into electrical power is equal to the product of the terminal pressure and the current; hence the generator is working at unity power factor.

From this it can be seen that if a generator operating in parallel with other alternating-current generators at a certain load has its excitation reduced until the armature current is a minimum, the machine becomes loaded non-inductively. Increasing the excitation increases the E.M.F., causing E to travel further along E X and causing the current to lag; and similarly decreasing the excitation will cause the current to lead. It can also be seen that the excitation cannot be reduced so that P E becomes less than O X, for the generator will then fall out of step. By increasing P E greater changes of O E and hence of the excitation can be brought about without such a great effect on the current, and generators with large internal inductive pressure-drops will be comparatively insensitive to changes of excitation; hence they are not good for purposes of rapid automatic pressure regulation and call for considerable over-shooting on the part of the regulator.

There is no advantage to be gained by trying to lower the excitation of one generator so as to obtain unity power factor, since the generator would then have no wattless component to its load, so that if the external load were at all inductive, as is more than probable, the wattless component would have to be entirely taken up by the other generators. It is therefore better to arrange the excitation so that the wattless component of the load is shared equally among the generators, and one of the objects of automatic pressure regulation is to share out the wattless component of the load equally among the various generators.

Automatic Regulation of Alternators in Parallel.

The automatic regulation of alternators in parallel consists in the maintenance of constant busbar pressure

and the even distribution of wattless currents as indicated above. The busbar pressure is maintained by the regulators operated by the pressure of the busbars to which their pressure coils are attached directly or through pressure transformers.

If all the generators be similar and have similar exciter characteristic curves they may be controlled by a single regulator provided that the exciters are paralleled to ensure uniform excitation, without which regulation would be carried out by the circulation of currents between the generators, resulting possibly in demagnetization.

Better regulation is obtained by using a separate regulator for each alternator; it is then unnecessary to parallel the exciters and the individual regulators can be adjusted to compensate for peculiarities of their respective generators. In this case the regulators should have static characteristics. If the generators are unlike or are excited by dissimilar exciters it is quite feasible to regulate one or two generators and allow the others to trail.

For the proper distribution of wattless currents between the generators at the same time that constant busbar pressure is maintained, it is necessary that the regulators should be operated both by the pressure and the current of each generator; also each generator should have a separate regulator, with a pressure transformer, and a current transformer should be placed between the generator and the busbars in one of the phases to which the pressure transformer is connected. The regulators should be arranged so as to have static characteristics when operating without the current transformers.

If there is a phase displacement between the current and pressure of an alternator controlled as described above, the action of the current coil on the regulator will be modified proportionately to the phase displacement. The regulation by this arrangement will therefore not be uniform unless the power factor of the station is practically constant. In spite of this disadvantage there are many power stations supplying traction and colliery loads where this arrangement is operating very satisfactorily, although there are necessarily circulating currents between the generators.

A method of automatically controlling both the pressure and power factor of alternators operating in parallel and supplying rapidly fluctuating loads is due to Messrs. Brown, Boveri & Co. Regulators with astatic characteristics are employed, and the secondary coils of the several current transformers are connected in opposition, so that as long as there is an even distribution of load and of the wattless component no current flows from them to any of the regulators, which latter will be acting merely as pressure regulators. Any phase displacement, however, will be accompanied by a circulation of currents between the generators, so that the current transformers of the various generators will supply current to the current coils of their respective regulators, increasing and decreasing the excitation of the generators as required. This system gives an even distribution of the wattless component of the load between the generators independently of their types and sizes, and it is very satisfactory in the case of heavy and rapidly varying loads.

CASCADE CONNECTIONS.

By H. V. Henniker, Student.

(*Abstract of Paper read before the* Newcastle Students' Section *28th April*, 1913.)

One of the foremost problems in connection with the use of polyphase current for power purposes is the provision of suitable variable-speed motors. The disadvantages attending the usual arrangement of an induction motor with a variable resistance for adjusting the amount of slip are well known, and it is unnecessary to enter into a discussion of them here. In view of the incomplete state of development of the 3-phase commutator motor, however, the induction motor has been extensively used as a variable-speed machine; in fact, there has been no alternative in the case of large installations.

There have been many suggestions for varying the speed of an induction motor without the waste of energy entailed in the rotor resistance method, and probably the most important of these, at any rate for large powers, are the various applications of the cascade or series principle.

Cascade Connection of Induction Motors.

We may define the cascade system as an arrangement of an induction motor having in its rotor circuit a machine or machines which, in addition to providing the back electromotive force necessary to effect speed variation of the induction motor, can at the same time usefully employ the slip energy which would otherwise be wasted in resistance. The original arrangement, as suggested independently by Steinmetz in America and Görges in Germany so long ago as 1897, is shown in Fig. 1. Connected in series with the rotor of the induction motor of which the speed is required to be varied is another induction motor, known as the auxiliary or regulating motor. The function of this auxiliary motor is to provide a back electromotive force and to employ the slip energy of the main motor usefully. The rotors of the two machines are mechanically coupled, and by this means the energy of the auxiliary motor is added to that of the main motor. Such a combination has a definite synchronous speed, which is quite different from the synchronous speed of the main motor or auxiliary motor when running alone. The synchronous speed of a cascade set depends upon the number of poles of both motors, and the following considerations should make this clear.

At the moment of switching on, the frequency of the supply to the stator of each machine is the same, since the rotor of the main motor is stationary. As the set gains

speed, however, the frequency of the rotor currents in the first motor decreases, *i.e.* the frequency of supply to the second stator decreases. Thus in the second machine the speeds of the rotating field and of the rotor become more nearly equal, and clearly there is some point at which they would be the same. The speed at which the second motor is rotating in synchronism with its field is the limiting speed of the set and may be termed the "synchronous speed of the combination." This speed could be actually attained if the second motor were a true synchronous machine, or in the hypothetical case of a second induction motor having no rotor resistance; but in the present case a state of stability is reached when a speed only slightly less than that of the rotating field of the second motor is attained, and at this point the combined torque is a minimum. The fundamental theory of the cascade connection of induction motors states that the speed of the common shaft must be such that the last motor is rotating almost synchronously with its field, and this holds true whatever the number of motors connected in cascade.

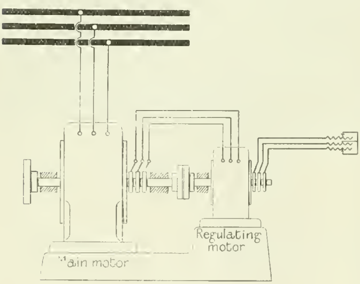


FIG. 1.

Consider, first, the case of the direct coupling, or a gear ratio of 1 : 1.

Let f = frequency of supply to first motor,
p_1 and p_2 = number of pairs of poles on first and second motors respectively,
n_1 and n_2 = speeds of rotating field in first and second motors respectively,
f_1 = frequency of rotor currents of first motor,
s_2 = fractional slip of second motor,
n = speed of common shaft.

When the combination is running we have from first principles—

$$f_1 = p_1(n_1 - n) \quad \ldots \ldots \quad (1)$$

Now f_1 is the frequency of the currents supplied to the stator of the second motor. Therefore $f_1 = p_2 n_2$. Transposing, we have—

$$p_2 n_2 = p_1(n_1 - n) \quad \ldots \ldots \quad (2)$$

Further, the slip of the second motor is given by $s_2 = (n_2 - n)/n_2$, or $n_2 = n/(1 - s_2)$. Substituting in equation (2) we obtain—

$$n = n_1 \frac{p_1(1 - s_2)}{p_1(1 - s_2) + p_2} \quad \ldots \ldots \quad (3)$$

and this is the actual speed of the shaft.

Now we have seen that s_2 is small; therefore neglecting this quantity we may write $n = n_1 p_1/(p_1 + p_2)$, or—

$$n = \frac{f}{p_1 + p_2} \quad \ldots \ldots \quad (4)$$

which is the synchronous speed of the combination. Thus the effect of connecting up the motors in cascade is to combine their respective numbers of poles, so that the synchronous speed of the cascade couple is the same as that of a single motor having $(p_1 + p_2)$ pole pairs. In general, with two motors connected up in this manner three speeds are available—

(1) The speed of the first motor (the second motor running idle).
(2) The speed of the second motor (the first motor running idle).
(3) The cascade speed.

Intermediate speeds under load can be obtained by the use of rotor resistance in the second motor. Pole-changing windings may also be provided, and other speeds made possible. If $p_1 = p_2$, then $n = \frac{1}{2} n_1$, and the cascade speed is half the speed of either motor when connected alone to the mains. In this case the arrangement is similar to the series-parallel control of continuous-current motors, since the machines may be used separately, in cascade, or in parallel.

Torque and horse-power.—In an induction motor the total number of watts W supplied to the rotor may be considered as consisting of (*a*) the useful watts, and (*b*) the losses.

The rotor efficiency is given by—

$$\eta_r = \frac{\text{useful watts}}{\text{useful watts} + \text{losses}}.$$

The torque is proportional to $\dfrac{\text{useful watts}}{\text{actual speed of shaft}}$.

Applying these principles to the first motor of a cascade set, let—

W = total watts supplied to rotor of first motor,
and w = watts usefully employed.

Then, from the well-known equation for rotor efficiency—

$$\eta_r = \frac{w}{W} = \frac{n}{n_1}, \quad \text{or} \quad w = \frac{W\,n}{n_1} \quad \ldots \quad (5)$$

Now if the speed of the main motor had been reduced to n by means of external resistance, we should be continually wasting the other component of W in resistance, this loss being almost entirely external in the case of anything more than a slight speed reduction. What the auxiliary motor really does is to provide a back electromotive force equal to the drop of voltage which would take

place across an external resistance necessary to effect this speed reduction. Moreover, this back electromotive force, instead of representing additional loss, is a measure of the mechanical energy exerted by the auxiliary motor. Thus, neglecting the small losses in rotors 1 and 2 and in stator 2, the power exerted by the second motor may be denoted as—

$$W(1 - n/n_1) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Since the actual speeds of the motors are the same, namely n, expressions (5) and (6) will be proportional to the torques exerted. Substituting for n/n_1 from equation (4) we find that the relative torques are such that $T_1/T_2 = p_1/p_2$, *i.e.* the motors share the torque in the proportion of the number of their poles to the total number of poles. The total torque is of course the sum of the individual torques, and neglecting losses is given by—

$$T = \text{constant} \times \frac{W}{n} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

It is of course to be understood that motor 2 cannot strictly be looked upon as a non-inductive resistance.

As regards horse-power, it is clear that this is limited by the rating of the first motor, since the second motor only takes up energy proportional to the regulation of the first motor, whatever the actual rating of the second machine may be. The latter would of course be designed according to the maximum regulation required for the former.

Efficiency.—The efficiency of a cascade set may be determined as follows:—

Let P = power drawn from mains,
P_1 = power exerted at shaft.

Then P_1 = mechanical energy of main motor + mechanical energy of auxiliary motor.

$$= P\,e_1(1 - a) + P\,e_1\,e_2\,a \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where e_1 = efficiency of main motor,
e_2 = efficiency of auxiliary motor,
a = speed regulation of main motor.

Then overall efficiency $= P_1/P = e_1 - e_1 a + e_1 e_2 a$ . . (9)

As regards losses, the losses in the first machine are relatively the higher, and Hobart* has suggested that each motor should be alternately connected to the mains. This would be satisfactory in the case of two similar motors so long as both are wound for the supply voltage. In the case of a smaller second machine, however, the rating of the set will become less if the change of connections takes place; moreover, the frequency in the circuit connecting the machines will be higher and the total iron loss greater, causing a decrease in efficiency and a greater temperature rise. The cascade speed will of course remain practically the same in either case.

Gear ratio.—The case where gearing is used between the machines requires special treatment. As before, the second machine must rotate almost synchronously with its field; thus the effect of the gear will be to alter the slip of the main motor.

* H. M. Hobart. "Electric Motors."

Let the gear ratio be such that $N_1/N_2 = K$,

where N_1 = actual speed of first motor,
N_2 = actual speed of second motor.

From the equation for rotor frequency—

$$\begin{aligned} f_1 &= f - p_1 N_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10) \\ &= p_2 n_2, \\ &= p_2 N_2, \text{ neglecting slip of second motor,} \\ &= p_2 N_1/K \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11) \end{aligned}$$

Equating (10) and (11) we have $N_1 = \dfrac{f}{p_1 + p_2/K}$ . . (12)

The speed of the second motor is obviously $1/K$ of this.

Differential Concatenation.

The foregoing calculations have been based on the assumption that the field in each motor revolves in the same direction. If the leads to the second machine are crossed so that the field in this machine rotates in the opposite direction to that in the first, the synchronous speed of the set will be that of a motor having poles equal to the difference of the individual poles, and is such that—

$$n = \frac{f}{p_1 - p_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

The torque of the set will be given by the difference of the individual torques, but the aggregate horse-power remains the same as for direct concatenation. The above equation may be deduced in a similar manner to that already given for direct concatenation, provided a proper convention is preserved with regard to which is positive and which negative rotation, but the theoretical considerations involved are outside the scope of this paper. Also the equations require careful interpretation according to whether the first motor is that having the greater or lesser number of poles.* It may be mentioned that if the motor with the greater number of poles is connected to the line, the set will not of its own accord reach cascade speed, since the speed of synchronism of the first motor is lower than the cascade speed. It will therefore be necessary to run up by connecting the machine having the smaller number of poles to the line and to change over to the normal connections when the cascade speed is nearly attained.

It is not necessary to limit the set to two motors. For instance, the synchronous speed of an arrangement consisting of three motors, the first two being in direct and the second and third in differential connection, may be shown to be:—

$$n = \frac{f}{p_1 + p_2 - p_3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

With an arrangement of three motors 10 different speeds could be obtained; but such arrangements seem to be of purely theoretical interest.

It is well known that the behaviour of an induction motor is only altered as regards rotation if instead of the stator the rotor is wound for connection to the mains. In such a case the stator forms the secondary, and this being fixed and not able to follow the field, the rotor must

* *Electric Journal*, vol. 6, p. 422, 1909.

rotate in the opposite direction to the field. The limiting speed will be attained when the rotor runs at a speed equal to that of the field but in the opposite direction to it, since at this point the field will be stationary in space and there will be no electromotive force induced in the stator. In the cascade set we may connect the rotors electrically instead of connecting the first rotor to the second stator. To obtain, however, an additive effect of the poles, and in order that the torques of the machine may be in the same direction, it will be necessary to arrange the connections so that the field in the second machine revolves in the opposite direction to that in the first, otherwise the effect will be that of the differential method. Slip-rings may now be dispensed with, and the starting resistance may be inserted in the second stator. These are the underlying principles of the Hunt cascade motor, in which the two rotor and two stator windings are merged into two single windings.

Applications.

It has been stated that the method shows a higher efficiency than where the control is by resistance in the rotor circuit, since the only losses are those in the machines themselves. Against this, however, must be balanced the low power factor obtained with the ordinary cascade set. Two magnetizing currents have to be supplied; for, in addition to the magnetizing current necessary to produce the rotating field in the first motor, the first motor has to supply the wattless current of the second motor. Thus, although it is theoretically possible to run a large number of motors in cascade and so obtain many different speeds, power factor imposes a limit. In fact with large low-speed sets the advisability of connecting up even two motors in this manner is extremely doubtful. Whether the cascade system is desirable in any particular instance will depend upon circumstances. The following comparative figures are interesting in connection with the question of power factor *versus* efficiency. They refer to a fan installation in a German colliery.

System	Main Motor		Speed Regulation, 8 %		Speed Regulation, 26 %	
	h.p.	r.p.m.	Eff.	Power Factor	Eff.	Power Factor
Slip resistance ...	1,200	250	0·89	0·89	0·72	0·80
Cascade	1,200	250	0·94	0·75	0·92	0·62

Reference has just been made to the use of this method of control in connection with fan driving. As the workings of a mine extend the fans are required to run at higher speeds in order to deal with the increased volume of air. At week-ends also it is often not necessary for them to run at full speed. Two or three fixed speeds generally meet the case, and continuous speed control is unnecessary. Consequently the cascade system has achieved some popularity in this direction. A number of rolling mills in Sweden have been equipped with cascade control. An important requirement in connection with rolling-mill work is the adjustment of the no-load speed so as to ensure proper handling of the material at the beginning of a pass. Although the cascade system suffers from the defect of running back to synchronous (cascade) speed directly the load is removed (as is the case with a single motor), it is possible to obtain several no-load speeds by suitably choosing the numbers of poles. Also the characteristic of a cascade set is suitable for rolling-mill work, for the available energy on the shaft being constant for a given input, the torque varies inversely as the speed. It is not possible, either with the rotor resistance method or the cascade method, to compound for flywheel effect, except by the use of an automatic slip regulator.

The cascade system lends itself to traction owing to the possibility of regenerative braking when the set is artificially raised above cascade speed. The extent of this generator period depends upon the sizes of the machines, but can be extended by the use of rotor resistance in the second motor.* The best-known examples of cascade control for traction work are afforded by the locomotives running on the section of the Italian State Railways known as the Valtellina Railway. These locomotives, supplied by Messrs. Ganz & Co. of Buda-Pesth, have been fully described elsewhere.

Motor Converter.

A familiar example of a cascade connection for a purpose other than variable-speed work is afforded by the well-known La Cour motor converter. This consists of an induction motor connected in cascade with a rotary converter. The machines are rigidly coupled, and the rotor of the induction motor and the armature of the converter are connected in series. From the formula for the cascade speed the synchronous speed of a motor converter is given by $n = f/(p_m + p_c)$, where p_m = number of pairs of poles on motor, and p_c = number of pairs of poles on converter. This speed, moreover, will actually be attained, since the second machine is a synchronous one. At the cascade speed the rotor currents of the induction motor will drive the converter in an exactly similar manner to the armature currents of a synchronous motor, since the rotating field in the armature of the converter will be stationary in space relative to the poles of the machine. As in the case of two induction motors, a portion of the input is given out as torque at the induction-motor shaft, and the remainder is transmitted electrically to the second machine, in this case the converter. The generator portion of the machine therefore acts partly as a generator driven by the induction motor and partly as a converter driven by the rotor currents of the induction motor. On reference to the previous calculations it will be clear that—

$$\frac{\text{Mechanical power exerted by induction motor}}{\text{Power transmitted electrically to converter}} = \frac{p_m}{p_c}.$$

Modifications of the Cascade Principle.

It is obvious that it is by no means necessary to employ an induction motor as the auxiliary motor of a cascade set, and also that the slip energy need not necessarily be given up to the main shaft (though this is the only solution in the case of the induction-motor auxiliary). Consequently we find that there are many variations of the cascade

* Steinmetz. "Theory and Calculation of Alternating-current Phenomena."

principle, and that the whole field is covered by patents in all directions. It will only be possible to consider a few of the more important systems here.

It has been suggested that a synchronous motor be used as the auxiliary machine. Such an arrangement would allow of phase compensation. There are several obvious disadvantages, however, and the author can find no indication that the method has been employed. A more satisfactory solution is the adoption of a commutator-motor auxiliary, and such a motor can be designed to lend itself admirably to the purpose. The well-known Krämer and Scherbius systems both employ a 3-phase commutator motor to give the necessary back electromotive force, but they differ in the method of making use of the energy developed by the commutator motor. In both cases speed regulation of the main motor is obtained by varying the excitation of the commutator motor, and thus varying its back electromotive force. In the case of the induction-motor auxiliary there is only a small range of variable back electromotive force available, and, in general, if a speed higher than the cascade speed is desired the auxiliary motor must be disconnected. With the commutator motor, however, a far wider range of back electromotive force can be obtained, and the speed of the main motor can be controlled through a wide range without loss. The commutator motor can, moreover, be rendered entirely independent of the frequency of the current supplied to it, so that it is not necessary to couple it mechanically to the main motor. In the Krämer system, however, the machines are mechanically and electrically coupled as shown in Fig. 2. The slip energy is thus given out as energy at the main shaft, and at any load the torque will vary inversely as the speed.

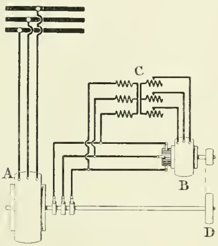


FIG. 2.—Krämer System.

A Main motor.
B Auxiliary commutator motor.
C Variable-ratio transformer.
D Belt drive.

In the method of Dr. Scherbius (see Fig. 3) the commutator motor is independent of the main motor, but is coupled to an induction generator which returns the greater portion of the slip energy of the main motor to the line in the form of electrical energy. In this case the horse-power of the main motor decreases with the speed, since the regulating set is not mechanically coupled. The torque of the main motor will therefore remain constant.

According to the characteristic required for either of these sets, the commutator motor is series wound and has a brush-rocking device, or is shunt or compound wound and has pressure regulation. In the case of the shunt winding any no-load speed may be obtained, and the speed will vary only slightly with the load. With a compound winding on the regulating motor the speed of the main motor may be made to decrease by any desired amount as the load increases. The figures show the shunt arrangement, which is more commonly employed. The Scherbius system is particularly applicable to the driving of large centrifugal machines in which the horse-power required greatly diminishes with the speed. The Krämer system is recommended for rolling mills, but for cases in which wide regulation is required it is generally preferable to adopt the former system. The commutator motor is of special design to meet the requirements of the case, and has the characteristics of a continuous-current machine. Moreover, by means of a special form of field winding it is possible to compensate for lag in the main motor.* This machine must not be confused with the Scherbius phase advancer.

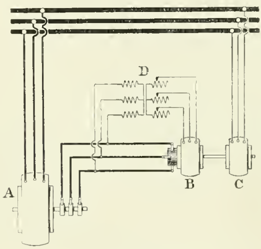


FIG. 3.—Scherbius System.

A Main motor.
B Auxiliary commutator motor.
C Induction generator.
D Variable-ratio transformer.

For purposes of comparison the following table may be given. The figures refer to a mine fan installation in Westphalia. The main motor is a 5,000-volt, 3-phase, 50-cycle machine, the commutator motor is built for 200 k.v.a., and the induction generator for 85 kw.

System	Main Motor		Speed Regulation, 8 %		Speed Regulation, 26 %	
	h.p.	r.p.m.	Eff.	Power Factor	Eff.	Power Factor
Scherbius ...	1,000	363	0·90	1·0	0·83	0·98

There is seen to be a great improvement in power factor but a slight reduction in efficiency when compared with

* R. O. KAPP. The Scherbius motor and some methods of working it in cascade with induction motors. *Electrician*, vol. 65, p. 512, 1910.

simple cascade control. Besides the driving of rolling mills and fans the Scherbius system has been used in connection with flywheel buffer sets to relieve a central station of heavy overloads, and it is interesting to note that a set is

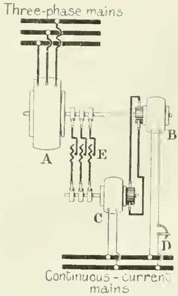


FIG. 4.—Krämer Converter System.

A Main motor. C Rotary converter.
B Continuous-current auxiliary motor. D Shunt regulator.
E Starter without neutral point.

to be employed for this purpose on the Valtellina Railway. Both systems have been applied to the driving of turbo-pumps, compressors, and blowers. Owing to the very high speeds often required in such cases, a commutator-motor set is here useful owing to the possibility of raising the speed above synchronism.

KRÄMER CONVERTER SYSTEM.

Another well-known system, also due to Mr. Krämer, is that employing a rotary converter. The slip energy is led to a rotary converter which converts it into continuous current. This current is led to a continuous-current motor which is mechanically coupled to the main motor, and the slip energy is thus given up to the common shaft. Speed variation is obtained by altering the excitation of the continuous-current motor. For instance, if resistance is removed from this excitation circuit the back electromotive force of the motor increases. This causes the continuous-current pressure of the rotary converter to rise, and with it the pressure at the slip-rings. To enable this to take place the slip of the main motor must increase and there will be a decrease in speed. When working with a flywheel, a compound winding may be provided on the continuous-current motor. The power factor may be adjusted by means of the converter field. It is possible to extend the speed above synchronism by reversing the excitation of the continuous-current motor when the set is running at full speed. This motor will then run as a generator and reverse the direction of rotation of the converter. A field will consequently be set up in the rotor of the induction motor revolving in the opposite direction, and the speed will rise above synchronism. Normally, however, the highest speed possible is limited by the lowest frequency necessary for stable running of the converter, say 3 cycles per second. This set is particularly useful in cases of wide regulation, and is at work in a number of large rolling mills.

HEATING OF BURIED CABLES.

INTRODUCTORY.

Last year the Council announced that it had appointed a Research Committee to promote and organize research on electrotechnical matters. The lack of sufficient data on the temperature rise of mains and cables buried in the earth was brought to the notice of the Committee and a Sub-committee was appointed to consider this matter. The Sub-committee was of the opinion that additional data were required, especially in those cases where the cables are buried and protected in the manner usually employed in this country; and the Sub-committee considered that experimental tests should be made in order to obtain these data.

On the recommendation of the Research Committee the Council decided to make a grant in aid of a research on the Heating of Buried Cables.

The Sub-committee has had a careful investigation made of the previous work which has been done and of the matters which require further investigation. A summary of the present knowledge on the subject has been prepared for the Sub-committee by Messrs. S. W. Melsom and H. C. Booth and is reproduced below, so that the members of the Institution may be able to judge of the present position and may make suggestions for consideration by the Committee.

The research will be divided into two parts. The first part will consist of a series of tests which will be carried out at the National Physical Laboratory. Lengths of cables of various sizes will be laid on different systems in the Laboratory grounds, and a number of tests will be made on the temperature rise of these cables under various conditions, and the soil constants, etc., will be determined. The second part of the research will consist of tests on actual mains under as nearly as possible practical conditions.

The facilities for these tests will be available owing to the courtesy of many of the supply authorities and others who have offered, on the invitation of the Sub-committee, to co-operate by allowing tests to be carried out on their networks.

The following provisional programme, prepared by the National Physical Laboratory, indicates the points which it is hoped to elucidate by the present research.

The Sub-committee will welcome any suggestions which may be of assistance in bringing the work to a successful conclusion. W. D.

REPORT OF THE NATIONAL PHYSICAL LABORATORY.

From the summary (see below) of the experimental work already done it will be seen that while the constants for armoured cables laid direct in the ground have been fairly well determined, there is practically no information available regarding cables drawn into conduits or laid solid in bitumen.

In considering the German tables for armoured cables laid direct in the ground in relation to the conditions obtaining in this country, it is probable that such important factors as the depth of laying, the amount of moisture in the soil, the temperature of the soil, etc., will be rather different.

In the absence of any knowledge as to the requisite thermal constants it is obviously impossible to produce from the information already published a table of permissible currents for cables laid solid in bitumen or drawn into ducts. Even for armoured cables laid direct in the ground, owing to the possible difference of the important factors mentioned, it would be necessary to re-determine the constants before the formulæ could be applied. It must also be pointed out that in arriving at these formulæ it has been necessary to make certain assumptions which render it doubtful whether they can be regarded as of greater validity than empirical formulæ. Thus, there is considerable doubt involved in assuming the surface of the ground to be an isothermal surface. This certainly cannot be the case where the size of the cable or of the surrounding duct is more nearly comparable with the depth of laying than is assumed in the mathematical treatment.

Further, even where the mathematical conditions are better realized as in the case of armoured cables laid direct in the ground, on account of the different conditions as regards the amount of moisture at various depths and other causes it cannot be definitely assumed that the surrounding soil is even approximately homogeneous in its thermal properties.

Some preliminary experiments made at the Laboratory, the results of which were given in a previous paper,* show that the heating may differ under various conditions of laying by as much as 100 per cent, and in the discussion of the paper Mr. Beaver gave some curves showing the same order of difference.

Another important factor to be borne in mind is the rate of heating and cooling of a cable and its relation to the load factor.

The more important points to which the research should be directed are as follows :—

(1) To obtain definite information as to the temperature of, and the moisture in the soil.

(2) Determination of the thermal constants of the soil, of the cable coverings, and of the various ducts.

(3) The heating of cables when laid (*a*) direct in the ground, (*b*) solid in bitumen, and (*c*) drawn into ducts, the external thermal conditions being the same.

(4) The temperature attained by mains in actual service and the load factor of the cables. (This would, it is expected, give also valuable information as to the rate of heating and cooling of cables laid in various ways.)

(5) To determine the watt losses in different types of cable with alternating current.

* S. W. Melsom and H. C. Booth. The heating of cables with current. *Journal I.E.E.*, vol. 47, p. 711, 1911.

SUMMARY OF THE THEORETICAL AND EXPERIMENTAL WORK ALREADY PUBLISHED ON THE HEATING OF BURIED CABLES.

By S. W. Melsom, Associate Member, and H. C. Booth.

Introduction.

The theory of the rise of temperature of a buried cable appears to have first been given by Kennelly.* The surface of the conductor itself is an isothermal surface, and if θ be the excess of temperature of this surface above that of some other surrounding it, H the heat generated per unit time in unit length of the cable, R the resistance to heat transference of the space bounded by these two isothermal surfaces and two planes perpendicular to the cable at unit distance apart, then we have $H = \theta/R$. Now we may divide R into two parts, S and G, where S is the resistance of the insulating and other coverings surrounding the wire, G that of the material—earth, sand, etc.—between the outer covering of the wire and the external isothermal. We have then $H = \theta/(S + G)$.

As to S, in the case at least of a single core of diameter d with a single outer covering of diameter d_1 and heat resistivity σ_1, its value is $\frac{\sigma_1}{2\pi}\log_e\frac{d_1}{d}$, while if there be a number of concentric coverings of diameters $d_2, d_3 \ldots d_n$ of heat resistivities $\sigma_2, \sigma_3 \ldots \sigma_n$, we have—

$$S = \frac{1}{2\pi}\left\{\sigma_1\log_e\frac{d_1}{d} + \sigma_2\log_e\frac{d_2}{d_1} + \ldots + \sigma_n\log_e\frac{d_n}{d_{n-1}}\right\}$$

a formula employed by Teichmüller. This formula can be simplified if any of the layers are good conductors, for then for such a layer σ vanishes; while if the insulating materials between these conducting layers, *e.g.* in a concentric cable, be the same, σ is for these the same; thus in a concentric cable we might have $\sigma_2 = \sigma_4 = \sigma_6 = 0$; $\sigma_1 = \sigma_3 = \sigma_5 = \sigma_k$, say; thus—

$$S = \frac{\sigma_k}{2\pi}\left\{\log_e\frac{d_1}{d} + \log_e\frac{d_3}{d_2} + \ldots\right\}$$
$$= \frac{\sigma_k}{2\pi}\log_e\frac{d_1,\ d_3,\ d_5\ \ldots}{d,\ d_2,\ d_4\ \ldots}$$

For a multicore cable non-concentric, Mie has shown how to deduce a corresponding expression.

As to G, various suppositions have been made. Kennelly supposes that we may consider the earth as a plane isothermal surface; and treating the problem by the method of images, as in Foster and Lodge's paper,† arrives at the result that—

$$G = \frac{\sigma_e}{2\pi}\log_e\left\{\frac{2l}{d_n} + \sqrt{\left(\frac{4l^2}{d_n^2} - 1\right)}\right\}$$

where σ_e is the thermal resistivity of the soil, d_n the diameter of the external covering of the cable, and l the depth below the surface of the ground of a point in the cable, not far removed from its centre and coinciding with the focus of the system of isothermals of which the cable forms one. In the practical application of theory the point may be taken as on the axis of the cable. Moreover, the ratio l/d_n is large in practice—l may be about a metre and d_n some 2 or 3 cm.—thus $4l^2/d_n^2$ is large compared with unity, and we may write—

$$G = \frac{\sigma_e}{2\pi}\log_e\left(\frac{4l}{d_n}\right).$$

In this form the formula is used by Teichmüller and others.

A different assumption is that the isothermals form a system of cylinders round the wire, and that we may assume that a cylinder with the axis of the cable as centre and of radius l which just touches the earth's surface, therefore above the cable, has the temperature of the surface. On this assumption

$$G = \frac{\sigma_e}{2\pi}\log_e\frac{2l}{d_n}.$$

This is used by Apt, Humann, and, with a slight modification, by Wilkens. These writers also neglect the term S in comparison with G, thus assuming that the thermal resistance of the insulating coverings is small compared with that of the earth. If, however, the two terms are evaluated for some actual cases, it appears (p. 783) that S and G are of the same order of magnitude. Again, the assumption of cylindrical isothermals round the cable is not justifiable: the cable is not under symmetrical conditions all round, and while experiments show that the surface temperature above a cable may be affected by its presence to some extent, Kennelly's assumption that the earth's surface is isothermal probably expresses the facts fairly closely.

This theory, then, of cylindrical isothermals will give too low a value for the resistance, and will lead to the inference that a given current will produce a smaller rise of temperature than is actually found to be the case, and in the Report of the Commission of the Verband deutscher Elektrotechniker in 1907 its authors accepted Kennelly's theory, as extended by Teichmüller, as giving a better representation of the facts.

Thus, so far as an isolated single-core or concentric cable laid direct in the ground is concerned, if we know the diameters of the conductor and its coverings and the thermal resistivities of these and of the ground, we have the material for calculating the rise of temperature due to any current. If we can neglect the term S, both formulæ can be simplified, since the values of the ratio d_n to l occurring in practice are such that for considerable variations in the value of either of these quantities the terms $\log_e 4l/d_n$ and $\log_e 2l/d_n$ are practically constant, as is illustrated on p. 782. Thus Apt's formula becomes

$$H = \frac{2\pi\theta}{\sigma_e\log_e 2l} = k\theta, \text{ say.}$$

Now $H = 4\rho I^2/\pi d^2 = \rho I^2/A$, where ρ is the resistivity of the conductor. Thus $I = \sqrt{k\theta A/\rho} = \gamma\sqrt{A}$ if $\gamma = \sqrt{k\theta/\rho}$, a constant for a given rise of temperature θ. On Kennelly's theory, omitting S we get the same form, but the value of γ would be decreased in the ratio $\sqrt{\log(2l)/\log(4l)}$.

If the term S be included no such simplification is possible. The problem of a number of cables close together of various sizes and each carrying its own current is much more complex, and for this data are wanting.

* A. E. Kennelly. On the carrying capacity of electric cables submerged, buried, or suspended in air. *Electrical World*, vol. 22, p. 183, 1893.

† *Philosophical Magazine*, 1875.

Reference should be made to Mie's paper which deals with the case when the current is the same in each branch of a multicore cable.

A more detailed account of the various experimental investigations follows.

Symbols Employed.

The various authors have naturally used different symbols in their mathematical treatment of the problem. In order to facilitate a comparison of the various formulæ, the following common list of symbols has been prepared and used as far as is possible throughout the abstracts.

I = Current, in amperes, for a single cable.
I_2, I_3, etc. = Current which each conductor in a concentric or multicore cable can carry.
ρ = Resistivity of the metal of the conductor in ohms per square millimetre at the temperature of working.
A = Cross-section of conductor in square millimetres.
θ = Temperature rise in the conductor in degrees Centigrade.
σ_e = Thermal resistivity of the material of the soil in electrical measure at a temperature corresponding to the mean temperature elevation.
σ_k = Thermal resistivity of the insulating material and covering of the cable in electrical measure.
$m = \sigma_k/\sigma_e$.
d = Diameter of the conductor in millimetres.
$d_1, d_2, d_3 \ldots$ = Diameters of the successive layers of the insulating material, sheathing, armouring and protective wrappings in millimetres.
d_n = Outer diameter of finished cable in millimetres.
Z = Number of conductors in a concentric or multicore cable.
l = Depth of the cable axis below the surface of the ground in millimetres.

Dr. Kennelly discusses* the theory of the subject and describes the practical experiments which he had made at the Schenectady Works of the General Electric Company. Kennelly's theoretical treatment of the subject, which has been followed by several subsequent investigators, has been fully dealt with in the introduction. It is an essential part of his theory that the surface of the ground should be supposed to be an isothermal. From experiments with a 750-ampere cable buried at a depth of 1 metre, he found that the temperature elevation at the surface of the ground immediately over the cable would differ from the normal by less than 2° C., even ignoring the greater reducing influence of the wind, etc.

Experimenting under working conditions on a particular type of cable (insulated with Siemens' compound and lead covered), Kennelly found values for the two thermal resistivities involved, viz. $\sigma_k = 750$; $\sigma_e = 50$. These values are most conveniently expressed in electrical units, *i.e.* a centimetre cube has unit resistivity when 1° C. difference of temperature between two opposite faces produces a steady flow of one Joule of heat per second.

* *Loc. cit.*

In order to deal with cases where two or more cables are laid in the same trench, Kennelly gives curves and tables which enable the position of the isothermal surfaces in the region surrounding the cable to be determined. In addition to the heat developed by the current which it carries, each cable will assume the temperature corresponding to the isothermal at that place, due to the presence of a neighbouring active cable. If there is more than one such cable the separate effects of each must be superposed. This involves as a further assumption that the introduction of the neighbouring cables does not materially affect the homogeneity of the thermal field, an assumption which is only valid if each cable is small and at a distance of at least 10 to 20 diameters from its fellows. Kennelly's experiments prove that with this restriction the assumption was very fairly justified. Observations made on cables horizontally separated by a distance of 11·4 diameters in the same trench showed that the temperature of one cable which was kept inactive acquired in 3 hours 38 per cent of the temperature elevation present in the sheath of its active neighbour, while the isothermal passing through the region occupied by the inactive cable indicated a 42 per cent elevation. The difference was probably due to the fact that 3 hours is not long enough for the isothermal to become permanently established. In this connection the influence of duration upon the temperature elevation becomes a very important factor. Strictly the maximum elevation is only attained after an indefinitely long period of activity. In the light of more recent experience it is doubtful whether in any working cable system this condition will be even approximately attained during the period of maximum load, which in practice is rarely longer than 3 to 4 hours daily.

Wilkens* proposed the following formula for the current which produces a given temperature rise :—

$$I = \sqrt{\frac{\theta\, 57\, \pi\, (d_n + l_o)\, A}{l_o}}$$

l_o in this case is the distance from the cable of a point in the surrounding medium at which the heating effect may be regarded as zero. If a definite value is assigned to θ, then since $(d_n + l_o)/l_o$ is in practice approximately equal to unity, the formula may be simplified to $I = C\sqrt{A}$, where C is a constant having for one of its factors the thermal resistivity of the soil.

Wilkens remarks on the length of time required before a stationary condition is attained. In his practical determinations of the value of the thermal resistivity constant he used a horizontal iron tube filled with oil and electrically heated. This tube was surrounded by the material under investigation. Wilkens considers 45° C. as the permissible upper limit of temperature, and taking the mean temperature of the earth as 15° C. he therefore obtains 30° C. as the maximum permissible temperature rise. Wilkens tested his results on a normal heavy-current system with cables laid direct in the ground. A 24-hours' run was taken and three types of cables were investigated :—

* K. Wilkens. Ueber die Erwärmung unterirdische elektrischer Leitungen. *Elektrotechnische Zeitschrift*, vol. 21, p. 413, 1900.

(1) An iron-armoured lead-sheathed single cable of 3,300 m. length and 120 sq. mm. cross-section, carrying 252 amperes.
(2) A cable of 2,400 m. length, 400 sq. mm. cross-section, carrying 560 amperes.
(3) A cable of 3,212 m. length, 725 sq. mm. cross-section, carrying 1,000 amperes.

The values obtained for l_o varied from 11 mm. to 46 mm. In order to allow for cases in which several cables are laid in one trench, Wilkens in drawing up his tables took $l_o = 50$.

A table of permissible currents is given, based on his theoretical formula. Values reduced from his experimental results agree with those given in the table to within about 10 per cent.

The temperature rise was measured by means of the resistance change of the conductor. In one case Wilkens found the temperature difference between the conductor and the outside of the insulation of the cable to be 3·2° C.

Apt was investigating the subject at about the same time.* His experiments were carried out in the laboratory of the cable works of the Allgemeine Elektrizitätsgesellschaft. Apt assumes, to simplify the mathematical treatment, that a cable buried in the earth is to be regarded as a cylindrical conductor surrounded by a concentric layer of earth having a radius approximately equal to the depth of the cable below the surface, and that the temperature of this layer is that of the surface. Also it is assumed that in consequence of the thermal conductivity of the surrounding medium the heat dissipation is only dependent on the temperature difference between the cable and the surface of the earth, and is nearly independent of the diameter of the cable. The term S of Kennelly's formula is omitted as being small.

For a temperature difference θ between the cable and the surface of the earth we have in this case the heat transference $H = \dfrac{\text{const} \times \theta}{\log \dfrac{2l}{d_n}}$.

The thermal resistivity of the soil is included in the constant.

Since $2l$ is in all cases much greater than d_n, the expression for H for a constant value of l, that is, for a fixed depth at which the cable is buried, only alters very slightly for quite considerable changes in the value of d_n, as is shown in the following table where $2l$ is taken equal to 1,000 mm., corresponding to a cable buried at a depth of 500 mm.

d_n in mm.	A in sq. mm.	$\frac{2l}{d_n}$	$\frac{1}{\log 2l/d_n}$
6·9	25	145	0·47
9·4	50	106	0·49
14·5	120	69	0·54
16·3	150	61	0·56
41·4	1,000	24	0·72

Thus a 40-fold change in the cross-section of the cable only causes a $1\frac{1}{2}$-fold change in the last term. With sufficient accuracy H may therefore be regarded as independent of d_n; and hence, as shown in the introduction,

$$I = \gamma \sqrt{A}$$

In his experimental determinations, Apt used continuous-current cables with jute insulation and lead sheathing. Each cable was placed in moderately moist sand contained in a tank of dimensions 6·8 m. × 1·5 m. × 1·5 m., and was wound backwards and forwards upon itself in order to conform more nearly to practical conditions, in which many cables are placed in one trench. There was everywhere a thickness of at least 0·5 metre of sand. Thus the condition of symmetry demanded by Apt's formula was approximately satisfied. The tests were continued for 24 hours, although a stationary condition was reached after a much shorter interval. The temperature rise was determined by the Kelvin double-bridge method. Five cables were investigated in this way, their cross-section ranging from 25 to 1,000 sq. mm. The values of the constants obtained by Apt varied by approximately 25 per cent with the same cable tested with different currents, and by about 16 per cent between the mean values of the various cables in the series.

Herzog and Feldmann* gave the result of investigations, including the case of concentric and eccentric cables, which appear to have been largely theoretical in character.

In 1903, Humann† described the results of a very extensive series of tests made at the laboratory of the Felten & Guilleaume Company, on heavy-current cables buried direct in the soil. In each case a piece of cable at least 30 m. long and buried at a depth of 80 cm. was used. The soil was sand with a little loam. The time of test was usually six to ten hours, and in all 29 different cables were brought under investigation. Humann followed the general lines of Apt's theory, and, taking the equation $I = \sqrt{\theta A/\text{constant}}$ to which either Apt's or Kennelly's equation reduces if we neglect S, he set out to determine the values of the constant.

In the case of the concentric and multicore cables Humann makes the statement that a "multiconductor cable corresponds exactly to a single cable if as the cross-section we take the total cross-section of all the conductors and as the current the sum of the currents in the separate conductors."

The values of the "constants" obtained by Humann vary over a somewhat wide range. In each series of cables tested there also appears to be a systematic variation depending on the size of the cross-section, which indicates the failure of the formula. Thus for cables of 2·5 sq. mm. cross-section a mean value for the "constant" is given as 0·02455, whereas in the case of a 300 sq. mm. cable it is given as 0·01356.

For the purpose of comparing the behaviour of buried cables with those suspended in air, Humann made comparative tests on two of the cables. He found that when suspended in an enclosure under similar conditions of

* R. APT. Ueber die Erwärmung unterirdisch verlegter Kabel. *Elektrotechnische Zeitschrift*, vol. 21, p. 613, 1900.

* J. HERZOG and C. FELDMANN. Ueber die Erwärmung elektrischer Leitungskabel. *Elektrotechnische Zeitschrift*, vol. 21, p. 783, 1900.

† P. HUMANN. Ueber die Erwärmung in Erdboden verlegter Starkstromkabel. *Ibid.*, vol. 24, p. 599, 1903.

laying, the temperature rise was about twice as great as when buried direct in the ground.

Humann also investigated high-tension cables. Eight different types were tested, but this number was not thought sufficient to warrant any general conclusions being drawn.

The tables and rules proposed by Humann were the subject of considerable criticism, which, however, turned principally on the limits of temperature rise adopted or recommended by Wilkens, Apt, and Humann respectively.

In 1904 appeared the load tables of the Wire and Cable Commission,* which applied to the case of one cable or two cables lying close together at the usual depth (70 cm.). The temperature rise allowed is 25° C. The tables are derived from the formula—

$$I = 11{\cdot}55\sqrt{\frac{A\,\theta}{\log 4\,l/d_n}},$$

which can readily be deduced from Kennelly's work by neglecting the term S and adopting certain values for the thermal resistivity.

Kath † explains the reasons which led the Wire and Cable Commission to adopt the formula and the constant 11·55. He discusses the results of some experiments on nine samples of 50 sq. mm. cables supplied by a union of the leading German cable firms. Among the objects of the investigation were the influence of the weather, the humidity of the soil, etc. The common experience of the Commission appointed by the Union was that the moisture of the soil was a principal factor in determining its thermal resistivity. In two experiments with soil of which the humidity was in one case 15·9 per cent and in the other 22·5 per cent, the temperature rise of cables buried in it was 11·5 per cent lower than with similar tests in dry soil. In these experiments some attempt was made to study the special case presented where several cables were grouped together. The nine cables were placed thus

ooo
ooo
ooo

and the nature of the curve showing the temperature rise with time when a current of 200 amperes was flowing was compared with its appearance when only one cable was carrying this load. The two curves show a striking difference. In the case of the single active cable the curve has become almost horizontal, showing that the stationary condition had been practically attained. Where all the nine cables were active, the curve, besides showing a 25 per cent greater temperature elevation, is still rising after a seven hours' run. For this reason it was considered that a run of at least 15 or 20 hours would be necessary in the investigation of cables laid in groups.

The temperature of the ground varies between 0° C. and 20° C. due to natural causes. This, and the fact that the placing of several cables in one trench may easily result in the temperature rise for a single cable being exceeded by 10° C., constituted a difficulty in deciding whether the maximum permissible temperature should be taken as 40 C. or 50° C. As a compromise it was suggested that the permissible current where several cables are placed together should be three-quarters of that allowed for a single cable, and this was adopted by the Commission.

In 1904 Teichmüller called attention in the *Elektrotechnische Zeitschrift* * to the deficiencies of the previous formula, and brought forward a more complete theory of the heating of cables, based on Kennelly's work, leading to the formula—

$$I = \frac{C}{\sqrt{\rho\,\sigma_c}}\sqrt{\frac{A\,\theta}{m\log\frac{d_n'}{d} + \log\frac{4l}{d_n}}}$$

where m is the ratio of the thermal resistivity of the cable insulation and covering to that of the earth ; and where

$$C = \sqrt{\frac{2\,\pi\,10^{-2}}{2{\cdot}303\times 10^{-4}}} = 16{\cdot}52.$$

In this case d_n' is the "reduced" outer diameter of the cable, *i.e.* the outer diameter of the cable d_n multiplied by a factor h which is equal to $d_1 d_3 \ldots / d_2 d_4 \ldots$

Thus these formulæ, as is shown in the introduction, take into account the interposition in the cable of layers of materials, such as lead covering and steel armouring, which in comparison with the insulation and the protective wrappings are held to have a negligible thermal resistance. The term h varies with different sizes of cables from about 0·67 to about 0·83.

The relative importance of the two logarithmic terms may be seen by taking the dimensions of a typical cable. Thus taking a particular 70 sq. mm. cable we have $d_n'/d = 21/10$, $d_n = 30$, $l = 1{,}000$ mm., and $m = 500/50$, then

$$m\log d_n'/d = 10\log 2{\cdot}1 = 3{\cdot}22$$
$$\log 4\,l/d_n = \log 4000/30 = 2{\cdot}12.$$

Thus the inclusion of the term $m\log d_n'/d$ increases the denominator from approximately 2 to 5.

The difference between the load tables calculated by this formula and the old tables is about 10 per cent, except for cables exceeding 500 sq. mm. (0·75 sq. in.) section, where it rises to 15 per cent.

Teichmüller shows how this formula can be adapted to the case of concentric cables. For concentric cables—

$$I = 1/\sqrt{\lambda Z}\times I_{\text{single}}$$

where I = current which one conductor will carry ;
Z = number of conductors, all naturally of the same cross-section ;
I_{single} = current which an ordinary single cable can carry at the same temperature elevation and under the same conditions ;
λ = factor depending on the dimensions of the cable. (For cables of ordinary construction the following are good mean values : for twin concentric cables : $\lambda = 0{\cdot}92$; for triple concentric cables : $\lambda = 0{\cdot}77$.)

The validity of these formulæ Teichmüller considers to have been sufficiently established by such observations as were available, and especially those made by Humann as previously described. In the development of his formula

* *Elektrotechnische Zeitschrift*, vol. 24, p. 464, 1903.

† H. KATH. Belastungstabelle für einfache Gleichstromkabel. *Ibid.*, vol. 25, p. 969, 1904.

* J. TEICHMÜLLER. Zur Theorie der Kabelerwärmung. *Elektrotechnische Zeitschrift*, vol. 25, p. 933, 1904.

Teichmüller assumes that the surface of the ground over the cable is an isothermal surface.

He also considered that there was then (1904) need for further experiments in the following directions :—

(1) The thermal resistivity of the insulation and covering and its dependence on temperature.
(2) The thermal resistivity of the soil in various conditions.
(3) The temperature rise of the surface of the earth in various conditions in comparison with the temperature of surrounding points.
(4) Whether the circumstance that the surface of the ground cannot be an exact isothermal has any considerable influence on the nature of the function $I = f(A)$.

A further contribution to the subject was that of Apt and Mauritius.* Three-core stranded 1,000-volt cables with iron armouring and fibrous insulating material were selected for these tests. They were placed in an iron tank and surrounded by sand so that there was everywhere a thickness of at least 0·8 metre of sand between the cables and the side of the tank. The temperature of the conductor was measured by its resistance change, determined by the Kelvin double-bridge method, and the temperature of the lead sheathing was ascertained in the same way. The formula $I = \text{constant}\sqrt{A\,\theta/\log(2\,l/d_n)}$, in which a symmetrical distribution about the cable is assumed, was adopted and a series of tables was drawn up for three-core stranded cables. The temperature rise allowed was apparently 25° C., the value adopted by the Verband deutscher Electrotechniker. It was shown that the rule given by Humann for multicore cables (p. 782) is not justified except in the case of very small cables. The values obtained by experiment are much greater than what would be indicated by the rule given by Humann.

High-tension cables were also tested. The maximum permissible current was found to be smaller than for low-tension cables—in the case of the larger sized cables in an almost constant ratio of 0·76 or 0·77. Here again results were obtained which were not in accordance with the conclusions of Humann, and Messrs. Apt and Mauritius state it as their opinion that it is not practicable to draw up general rules or tables for high-tension cables since the practice of the various firms as regards material and thickness of insulation varies so widely.

Humann† discussed the case of three-core cables and gives the results of some experiments. His work appears to have been based on the mathematical theory of Teichmüller taken in conjunction with that of Mie,‡ who gave formulæ by which multicore cables could be reduced to the case of a single-core cable.

Humann's experimental investigations were in connection with some three-core cables of 30 m. length which were buried at a depth of 70 cm. and run for 10 hours with continuous current. A series of values for heating effect was obtained for six different cables ranging in size from 3×25 sq. mm. up to 3×240 sq. mm.

Humann's values obtained experimentally point to great variations in the value of the constant m, the ratio of the thermal resistivity of the cable covering to that of the earth. Thus for a cable of 25 sq. mm., m is 256; for a cable of 50 sq. mm., $m = 61$; and for a cable of 240 sq. mm., $m = 21$, as against values for m ranging from 11 to 15 determined or assumed by the previous investigators, Kennelly, Teichmüller, and Apt.

Humann in a later investigation also studied the effects produced by temperature fluctuations at the surface of the earth due to climatic causes. He found, as is well known, that even in strata only a few centimetres below the surface the range of such fluctuations was greatly reduced. Thus a fluctuation of 4° C. at the surface was reduced to a fluctuation of about 1° C. at a depth of 5 cm.

In a paper entitled "Die Materialkonstanten zur Berechnung der Kabel auf Erwärmung,"* Teichmüller in conjunction with Humann returns to the formula quoted on page 783. It had been proposed to simplify this formula by reducing the logarithmic numerator to one term, but this can only be done if the values of σ_k and σ_e, the thermal resistivity of the insulation and packing and that of the soil respectively, can be regarded as the same to a reasonable degree of approximation. The two authors therefore undertook an exact determination of these constants, the values of which were not known with any certainty.

The determination of the value of the constant σ_k, the thermal resistivity of the insulation and filling material, was based partly on specially devised experiments, and partly deduced from an examination of earlier results. It was considered to be of the first importance that practical conditions should be realized as closely as possible, as it was not improbable that pressure and position and mechanical treatment might affect the value of the constant. Bare lead-sheathed single cables of normal construction with impregnated jute or paper filling were therefore chosen. They were laid out on porcelain carriers so that the air had unimpeded access on all sides. A current was passed through the conductor and its temperature determined from the resistance by the usual double-bridge method. The temperature of the lead sheath was also measured in the same way by means of a small momentary testing current, the temperature coefficient of the lead having been specially determined. As a check method the temperature of the lead sheath was also determined by keeping a constant stream of water running over it. Practically identical results were obtained by both methods. It follows that under these conditions—

$$\sigma_k = C \times \frac{A\,\theta}{\rho\, I^2 \log d_n/d}$$

where $C = \dfrac{2\pi \times 10^2}{2\cdot303} = 272\cdot8$,

d_n = outer diameter of the insulation,
and d = diameter of the conductor.

The tests were continued for three or four hours in order to ensure constant conditions of temperature. The stationary condition was, however, attained in about two hours. Seven cables were tested, each with from 2 to 5 different values of the load current. The various values obtained for σ_k were in each case in good agreement, and the average

* R. Apt and C. Mauritius. Die Erwärmung unterirdisch verlegter Drehstromkabel. *Elektrotechnische Zeitschrift*, vol. 25, p. 1009, 1904.
† P. Humann. Über die Erwärmung von verseilten Dreifachkabeln in Erde verlegt. *Ibid.*, vol. 26, p. 533, 1905.
‡ G. Mie. Über die Warmeleitung in einem verseilten Kabel. *Ibid.*, vol. 26, p. 137, 1905.

* *Elektrotechnische Zeitschrift*, vol. 27, p. 579, 1906.

value for the seven cables was 644, the extreme values being 617 and 755. For all values of the temperature occurring under working conditions (over a range of 50° C.) the thermal resistivity according to Teichmüller and Humann may be regarded as practically constant. The average value of the thermal resistivity of the filling and packing material was found to be 570. The effect of moisture was also investigated. As a good average value of insulation and packing taken together $\sigma_k = 600$ may be adopted.

It had also been suggested that there was a "transition thermal resistance" at the common boundary of two different layers of material. This point had been discussed by Teichmüller in his book on the heating of cables.* To investigate the matter two cables each of 19·5 sq. mm. cross-section and 4 mm. insulation thickness were prepared. Each was exactly alike in every particular except that in one the impregnated paper was applied in two layers, separated by a thin layer of tinfoil, thus introducing two additional "transition boundaries." When tested the difference in the value of the thermal resistivity as determined from these two cases was found to be quite negligible.

In the determination of σ_e, the thermal resistivity of the soil or other substance by which a buried cable may be surrounded, a horizontal iron tube 383 cm. long and 20 cm. in diameter was employed. Through this was passed a brass tube of somewhat greater length, 5·2 cm. in diameter and 1 mm. thick. Clamps on the two projecting ends of this inner tube enabled a current to be passed along it to secure a suitable temperature elevation. The annular space between the two tubes was filled in turn with the various materials under investigation. The temperature of the outer tube was kept constant by a stream of water flowing over it. The materials investigated and the value of the thermal resistivities were as follows :—

Material		Value of σ_e in Electrical Units
Sand 0·4 % wetness (very dry)		320 mean value
„ 0·4 %	„	324 another determination
„ 4·4 %	„	81
„ 9·9 %	„	62
Normal soil 12 %	„	117
„ 11 %	„	102 by different apparatus
Dry gravel		229

Note :—The very dry sand and gravel are extreme conditions which do not apply in practice.

The values thus obtained were higher than had been expected from the results of tests made on cables laid in soils of this description.

Further investigations were made under practical conditions. For this purpose a spiral of constantan wire about 10 m. long was wound on a wooden pole and buried 70 cm. below the surface of the ground. A thermometer was placed at the middle of the pole, and other thermometers at points 30 and 50 cm. above the pole and also at a point 5 cm. below the surface of the ground. It was found that the temperature in the immediate neighbourhood of the wire, and even at 30 and 50 cm. away, did not become constant till after the elapse of 60 hours. Further investigations showed that 13 days were required for a really stationary temperature to be attained. Absolute values for σ_e were not obtained, the experiment being directed more to determining the time required for a stationary condition to be reached.

As a result of this investigation Teichmüller and Humann conclude that owing to the heat capacity of the earth and to the fact that the greatest time of loading is only a few hours, one-half of the mean value of the thermal resistivity of soft earth should be taken. Thus they propose for purposes of calculation that $\sigma_e = 40$ to 60.

In 1907 appeared the load tables of the Verband deutscher Electrotechniker* and "Notes on the New Load Tables for Cables laid direct in the Ground" by Teichmüller.† The Commission which drew up the load tables consisted of Uppenborn (President), Passavant, Apt, Humann, Teichmüller, and Klement. Teichmüller in his note states that the new load tables for cables laid in the ground were calculated by the following formula, which holds for all cables :—

$$I = \frac{C}{\sqrt{Z\rho}} \sqrt{\frac{A\,\theta}{\sigma_k \log \frac{d_n'}{d'} + \sigma_e \log \frac{4\,l}{d_n}}}$$

where $C = \sqrt{\frac{2\,\pi\;10^{-2}}{2{\cdot}303 \times 10^{-4}}} = 16{\cdot}52.$

For single cables the term d' would be d, as in the formula on p. 783. d' is derived from a theory given by Mie ‡ by means of which a multicore cable can be reduced to the case of a single cable. The formula given above combines the theories of Teichmüller and Mie, and this applies to single, concentric, and multicore cables. This formula and the tables based upon it are regarded as exact for the stationary conditions. It was noted by several experimenters that the stationary condition was not reached with certainty until after several days. The rise, however, after from 6 to 10 hours was very slow ; thus, roughly speaking, after 3 to 10 hours the conditions could be taken as being practically stationary.

It remained to determine from the available material the most probable values for σ_k and σ_e, and the Commission decided on the values $\sigma_k = 550$ and $\sigma_e = 40$.

The only experiments of which the results did not agree with those calculated from the formula were not further considered in view of the fact that one of the observers (Dr. Apt) expressed his agreement with the table founded on the formula. He explained that the difference was due to the fact that in the experiments made by himself and Mauritius the cables were not laid under practical conditions, but were in an iron basin.

The Commission were of opinion that the values chosen for σ_k and σ_e could therefore be regarded with special confidence as the best mean values, being accepted not only by the newer but by the older observers also (Kennelly, Herzog and Feldmann, Teichmüller, and Humann). The last-named observers did indeed find higher values in their

* J. TEICHMÜLLER. "Die Erwärmung der elektrischen Leitungen." Stuttgart, 1905.

* *Elektrotechnische Zeitschrift*, vol. 28, p. 823, 1907.
† *Ibid.*, vol. 28, p. 499, 1907.
‡ *Ibid.*, vol. 26, p. 137, 1905.

Laboratory experiments, getting a figure about double (see p. 785), but in their experiments on cables laid under practical conditions the lower values were also observed, and it is stated that the difference probably depends on the great heat capacity of the earth. In the first case the true stationary condition was reached, and in the last the *quasi* stationary, which corresponds more nearly to the practical conditions.

The temperature rise allowed for in the table is 25° C., as in the old tables. The maximum temperature allowed for cables is 50° C., and therefore the normal maximum temperature of the soil is taken as being 25° C. Teichmüller states that this temperature limit is to be regarded as a compromise between the cable manufacturers and the cable users. The latter regard higher temperatures as possible, the former will undertake no guarantee for such higher demands. The normal depth of laying is 70 cm. (2 ft. 3 in.).

No difference is made between direct and alternating current, it being stated that the losses due to the causes mentioned (hysteresis in the dielectric, eddy currents in the armouring, etc.) are, in general, small.

Wiring Rules adopted by the Verband deutscher Elektrotechniker.

*Table of Loads for Single-conductor Cables, at 700 Volts, with and without Pilot Wire, laid direct in the Ground.** (A table giving the equivalent cross-section in square inches has been added.)

Cross-section in sq. mm.	Cross-section in sq. in.	Current in Amperes
1·0	0·00155	24
1·5	0·00232	31
2·5	0·00387	41
4	0·0062	55
6	0·0093	70
10	0·0155	95
16	0·0248	130
25	0·0387	170
35	0·0542	210
50	0·0775	260
70	0·1085	320
95	0·1472	385
120	0·1860	450
150	0·2325	510
185	0·287	575
240	0·372	670
310	0·480	785
400	0·620	910
500	0·775	1,035
625	0·969	1,190
800	1·240	1,380
1,000	1·550	1,585

Note.—The advantage from the point of view of heating of subdividing the number of conductors as, for instance, to lay two small cables instead of one large one, is obvious from the table. Thus in current-carrying capacity—

Two 0·1 sq. in. cables will carry 1·3 times the current allowed for a 0·2 sq. in. cable. This ratio of 1·3 is approximately constant over a wide range of cable sizes.

* *Elektrotechnische Zeitschrift*, vol. 28, p. 824, 1907.

Table of Loads for Single-conductor Cables laid direct in the Ground. (The preceding table was plotted and the following values were taken from the curve.)

Cross-section in sq. in.	Current in Amperes
0·10	304
0·15	390
0·20	470
0·25	530
0·30	590
0·40	697
0·50	800
0·60	895
0·70	975
0·80	1,055
0·90	1,140
1·00	1,210
1·10	1,285
1·20	1,357
1·30	1,420
1·40	1,487
1·50	1,555

Tables of Permissible Current for Concentric and Multicore Cables, up to 3,000 Volts, laid direct in the Ground.

Cross-section of Each Conductor		Current in Amperes for Each Conductor			
In sq. mm.	In sq. in.	Concentric	2-core	3-core	4-core
4	0·0062	—	42	37	34
6	0·0093	—	53	47	43
10	0·0155	70	70	65	57
16	0·0248	90	95	85	75
25	0·0387	120	125	110	100
35	0·0542	145	150	135	120
50	0·0775	180	190	165	150
70	0·1085	220	230	200	185
95	0·1472	270	275	240	220
120	0·1860	310	315	280	250
150	0·2325	360	360	315	290
185	0·287	405	405	360	330
240	0·372	470	470	420	385
310	0·480	550	545	490	445
400	0·620	645	635	570	—

Tables are also given for cables working up to 10,000 volts. The difference between them and those given above is however less than 10 per cent. These tables hold so long as not more than two cables are laid together in the same trench.

In laying cables in channels or running a number of cables together in the ground or any such unfavourable conditions, it is advisable to reduce the maximum load to three-quarters of the values given in the tables.

Ferguson in a paper on "Underground Electrical Construction"* described some tests made with cables drawn into ducts. The tests were made in the laboratory, the ducts being surrounded by 6 in. of sand. The rise of temperature under these conditions was rather larger than

* *Transactions of the International Electrical Congress, St. Louis,* 1904, vol. 2, p. 266.

when the cables were supported in air. Since, however, the ducts were not buried in the ground, it would seem that the results are scarcely comparable with what might be expected under practical conditions.

Ferguson emphasizes the importance of making observations of the temperature of cables in actual use, and recommends that where a large number of loaded cables pass through one manhole it is well to have readings taken periodically to determine whether a temperature unsafe for the cable is reached.

The question of proper ventilation is also discussed in the paper. The author considers it to be important that ventilators should be frequently examined and cleared.

Kennelly and Shepard* made a series of determinations of the thermal resistivity of various grades of soil such as sand and gravel. For this purpose a copper wire was supported at or near the axis of an iron tube, the space around the wire being packed with the different soils. The iron tube was surrounded by a water jacket, the temperature at the outside of the tube being kept constant by a stream of water.

The test wire attained its maximum temperature under these conditions in rather less than 2 hours.

The following are some of the values obtained for the various grades of soil.

Material	Thermal Resistivity
Yellow sand (dry)	351
Fine white-quality sand (dry)	391
„ „ with 20 % of water	164
„ „ with 10 % of water	229
Fine sandy soil (dry)...	490
„ „ with 20 % of water ...	356

Lichtenstein † describes the results of some experiments on high-tension cables with the special object of determining to what extent the permissible current was affected by the extra thickness of insulation.

The cables were laid, a number in a trench, direct in the ground at a depth of 75 cm. The distance between the cables was about 7 cm. Some of the cables had conductors of iron wire, and the current in these was reduced in order to have the same loss in watts as in a copper conductor of similar size. Various types of cable, such as plain lead-sheathed, armoured, single, concentric, and three-core, were tested.

Lichtenstein found that the temperature rise in such cables with the currents prescribed by the German tables of 1907 for low-tension cables was in many cases considerably higher than the 25° C. limit allowed. Thus a normal high-tension cable 3×44 sq. mm. with 16 to 18 mm. thickness of insulation showed a temperature rise of 40·7° C. These discrepancies are held to indicate the necessity of special tables for high-tension cables, and Lichtenstein accordingly draws up load tables.

For high-tension (up to 30,000 volts) cables.

(1) For single conductor with 5 mm. thickness of insulation, both armoured and bare.

(2) For 3-conductor armoured cables with 17 mm. thickness of insulation.

* A. E. KENNELLY and E. R. SHEPARD. The heating of copper wires by electric currents. *Transactions of the American Institute of Electrical Engineers*, vol. 26, p. 969, 1907.

† L. LICHTENSTEIN. Versuche zur Bestimmung der Kabelerwärmung. *Elektrotechnische Zeitschrift*, vol. 30, p. 389, 1909.

Further experiments were made with two or more cables laid in the same trench loaded together. In the case of two cables separated by a distance of 21 cm. a temperature rise of 43° C. was obtained, as against 38° C. for a single cable under similar conditions of load. The additional 5° C. rise brought about by the presence of the neighbouring active cable was approximately equivalent to the additional temperature rise caused by an increase of 7 per cent in the current.

With three or more cables connected in series the results generally were held to justify the German rule in which it is recommended that in the case of a number of cables laid in one trench the load should be reduced to three-quarters of that for cables laid singly.

Mosman has given an account* of an extensive series of investigations made with an 81-way conduit system arranged 9×9. Only a few of the cables had actually been installed and apparently the special object of the investigation was to determine the proper size and current for the remainder. Only one portion of the system was actually underground, and here the depth of the upper surface of the concrete envelope, the section of which was approximately $4 \times 4{\cdot}5$ ft., was only $1\frac{1}{2}$ to 2 ft. below the surface of the ground. It does not therefore appear easy to derive any results capable of very general application from these investigations. The type of conduit system here in question is very unusual.

The underground section was about 260 ft. in length. An important test from the point of view of further investigation was in connection with the temperature variation along the cable, as showing the magnitude and extent of the end effect. It appears from Fig. 15 (p. 774) of the original paper that whereas the temperature at one manhole was approximately 25° C. and at the other 20° C., the temperature at a point 20 ft. from the first manhole was within 2 or 3 degrees of the maximum, which was about 42·5° C. At the other manhole the end effect was more marked, the temperature falling from 40° C. to 15° C. over a length of about 50 ft. The considerable diffusion of the heat from the end portions, brought about by convection through the large number of empty ducts by which the active cable was surrounded, was no doubt chiefly responsible for this, and shows how great this effect may become when forced draught is resorted to.

The tests were made with alternating current, and apparently some portion of the heat developed was due to induced currents in the lead sheathing. The conduits were of fibre laid in cement. The effects of ventilation were studied and the possibility of using a forced draught for cooling the cables is discussed.

L. Bloch in a paper read before the Elektrotechnische Verein † drew attention to the enormous increase in the watts lost and the temperature rise where alternating-current mains were laid singly in iron pipes. Curves and tables are given, showing the number of watts lost and the temperature rise for cables laid singly in iron pipes to be as much as four times that when the cables are laid direct in the ground.

Melsom and Booth ‡ gave curves showing the heating of

* C. T. MOSMAN. Notes on underground conduits and cables. *Transactions of the American Institute of Electrical Engineers*, vol. 31, p. 575, 1912.

† (Abstract) *Electrician*, p. 531, 1913.

‡ *Journal I.E.E.*, vol. 47, p. 732, 1911.

a 19/14 S.W.G. cable laid in the ground under different conditions.

The temperature rise in the cable with a current of 160 amperes was :—

(1) Laid direct in the ground = 8° C.
(2) Laid solid in bitumen = 14° C.
(3) Laid in a 3-in. earthenware pipe = 20° C.

Mr. C. Beaver in the discussion of the above paper gave some curves for a 0·5 sq. in. cable running at 1,500 amperes per sq. in. when laid under different conditions.

The temperature rise for some of the conditions of laying after running for ten hours was :—

(1) Armoured cable laid direct = 48° F.
(2) Lead-covered in asphalt trough = 53° F.
(3) " laid solid = 98° F.
(4) " drawn in = 85° F.

Conclusion and Remarks.

In considering the German tables and the work on which they are based it will be seen that while the mathematical work following on that of Kennelly is, for the case of armoured cables laid direct in the ground, fairly complete, certain of the assumptions which have been made and which materially affect the problem are open to criticism. For instance, the value of the thermal resistivity of the soil ($\sigma_e = 40$) taken for the purpose of the German tables is very different from the later values obtained by Kennelly. It seems clear that the German tables are based on what is assumed to be practical conditions and not on the ultimate stationary conditions, since the value of $\sigma_e = 40$ would under the stationary conditions appear to be more nearly the value obtained by Kennelly in 1907, *i.e.* approximately 200. Particulars are not given by the German experimenters as to the amount of moisture in the soil at the depth of 70 cm. at which their cables were buried. It seems probable that in the case of cables laid at a depth of less than 70 cm., owing to there being less moisture in the soil at this depth, the value for the thermal resistivity σ_e would be much greater than 40 and might approach 200. In the case of a typical cable the use of the value $\sigma_e = 200$ instead of 40 would reduce the permissible current by the order of 30 per cent.

There is apparently practically no information available in regard to the case of cables laid solid in bitumen or drawn into ducts. The preliminary results of Melsom and Booth and the curve given by Beaver show that very large differences can be obtained with different systems of laying. It is fairly obvious that the German rule of reducing the current to three-quarters of that allowed for a cable laid direct in the ground cannot apply to such cases.

The thermal conditions are particularly complicated in the case of a multi-way earthenware duct containing a number of cables. In addition to the mutual effect of neighbouring cables there are other important factors, the effect of which is little known. For instance, the thermal resistance of the layer of air contained in the duct around the cable under conditions where the effect of convection may be very small, is likely to be very high. Again, little is known of the thermal properties of the material of the duct itself, or of earthenware troughing containing bitumen. Moreover, a comparison between the figures published by a British firm of cable makers for cable drawn into 3-in. stoneware ducts, with the German tables for cables laid direct in the ground, shows a large difference, due apparently to the different conditions of laying. The British figures allow of a temperature rise of 50° C., while the German tables allow of a rise of 25° C.

Conductor Area, sq. in.	Permissible Current in Amperes	
	British, for Cables in 3-in. Conduits	German, for Armoured Cables Laid Direct
0·1	233	304
0·5	644	800
0·7	795	975
1·0	993	1,210

If we take, for purposes of comparison, the German recommendation for the case of cables in ducts, and reduce the figures for permissible current in the table to three-quarters, and also reduce the British figures to currents corresponding to a 25° C. rise, we have the following table :—

For Cable in 3-in. Conduits for a Rise of Temperature of 25° C.

Conductor Area, sq. in.	British	German
0·1	165	228
0·5	455	600
0·7	562	730
1·0	702	908

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[I.P.O.E.E. = Institution of Post Office Electrical Engineers.]

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OBITUARY NOTICES.

JAMES HERBERT CAWTHRA died in his 42nd year, as the result of a motor car accident on the 8th October, 1913. After serving his apprenticeship he went as Outside Assistant to Messrs. J. H. Holmes & Co., of Newcastle-upon-Tyne, and superintended the erection of complete electrical installations on board ship and in factories. He was for a short time an assistant in the mains department of the Newcastle-upon-Tyne Electric Supply Company. Following upon this he obtained experience as a sea-going engineer with several firms. He was appointed in 1893 Chief Assistant in the generating station of the Yorkshire House to House Electricity Company at Leeds, serving in the same capacity when the works were taken over by the Leeds Corporation. He left Leeds in 1900 on his appoinment as Borough Electrical Engineer at Swansea. After a short tenure of office he was appointed in 1901 Borough Electrical Engineer at South Shields. Subsequently he drew up a complete scheme for the electrification of the tramways. In 1911 he was appointed Superintendent to the Victoria Falls & Transvaal Power Company, in which capacity he was responsible for the operation of all the Company's generating stations. He was elected a Member of the Institution in 1904.

THOMAS CUSHING died in October, 1913, in his 73rd year. After a short period of service with the firm of Messrs. T. Cooke & Sons of York, makers of scientific instruments, he was appointed in 1867 to the post of assistant inspector of scientific instruments to the India Store Depot, ultimately becoming the chief inspector. In this capacity it was his duty to carry out tests in the early days of telegraph instruments; and later when heavy electrical machinery came into common use, the testing of this was also comprised in the duties of his office. He was the inventor of a new form of oil insulator which was patented and proved very successful. He was elected a Member of the Institution in 1881.

STEPHEN D. FIELD died at his residence in Stockbridge, Massachussetts, U.S.A., the 18th May, 1913. He was an inventor in many branches of electrical work, including telegraphy, and in 1879-1880 applied for patents for an electric railway, comprising a stationary generator, a trolley wire, an electric car, an under-running trolley, and bonded rails for the return circuit. In the latter year he constructed an experimental electric line in Stockbridge, and in 1883, in connection with Mr. Edison, operated an electric locomotive by a third-rail at the Chicago Railway Exposition. After his early work he paid little attention to electric railways, except in the later nineties, when, representing American capitalists, he had charge of the electrical equipment of the tramway system at Geneva, Switzerland. He was elected a Member of the Institution in 1877.

CHARLES THOMAS FLEETWOOD died in December, 1913, in his 75th year. He entered the service of the Electric and International Telegraph Company in 1854 and was connected with the Telegraph Department of the Post Office during the remainder of his professional career. He retired in 1902. In 1875 he contributed to the *Journal* of the Institution a paper on "Underground Telegraphs—the London Street Work," and again in 1887 one on "Underground Telegraphs"—the latter of which was awarded the Fahie Premium. He was elected an Associate of the Institution in December, 1872, and a Member in 1886; and he served on the Council in 1879.

ALFRED S. GILES died on the 22nd October, 1913, in his 48th year. He was for some time a member of the engineering staff of the Edison & Swan Company, leaving that firm in the early nineties when the installation department was given up. After five or six years on the staff of Messrs. Thompson, Ritchie & Co., he went to Blackburn in 1895 as Chief Engineer in the Corporation Electricity Department, and held that position until 1904 when he was appointed Engineer-in-Chief of the Cape Tramways. In 1911 he became Manager and Engineer-in-Chief of the Lisbon Tramways, a position which he occupied until his death. He was elected an Associate of the Institution in 1895, and a Member in 1900. He served on the Committee of the Manchester Local Section from 1901 to 1904, in which latter year he became Vice-Chairman. In 1906-7 he was Chairman of the Cape Town Local Section.

JOHN GOTT, who died at Brighton on the 8th March, 1914, was one of the pioneers in submarine cable engineering. He was born at Kendal, Westmoreland, in 1840, and entered the telegraph service early in life. His first employment was with the Electric and International Telegraph Company. In 1863 he went to Tripoli where he was employed in the operation of the first Mediterranean cable, later going to Malta on this same work. In 1864 he was selected to accompany the steamship *Great Eastern* as one of the electrical staff when that vessel made her first attempt to lay a transatlantic cable. In 1869 he accepted the position of Superintendent and Electrician at St. Pierre, Miquelon, when the cable of the first French Atlantic Cable Company was laid. In 1870 he transmitted wireless signals through a distance of about three miles at St. Pierre, Miquelon, using the earth as a conductor. In the same year he invented his fault-searcher coil. In 1881 he introduced a modification of Lord Kelvin's formula for testing measurements of the electrostatic capacity of condensers and cables; this is now used as a standard test and is known as "Gott's capacity test." In 1884, upon his retirement from the French Cable Company's service, he became Chief Electrician to the Commercial Cable Company, a position which he held until his death. In 1892 he devised the "Gott ratio arm," which made it possible to avoid the necessity for temperature corrections for the resistance of Wheatstone bridge coils by introducing coils of manganin for one of the ratio arms, and also made it possible to obtain measurements in modern units by means of a bridge wound to discarded

standards. Of greatest importance, however, was his recent invention, whereby he made it possible to communicate from the Pacific coast of the United States and Canada direct to Europe without the aid of human retransmission at intermediate station, cables and land lines being linked up and the ordinary Morse method of operation employed. He also latterly invented a new and improved system of quadruplex working. He was elected an Associate of the Institution in 1873, and a Member in 1877.

ROBERT KAYE GRAY, Past President, was born in June, 1851, and died on the 28th April, 1914. He received his early education in Greenock, entered University College School in 1865 and later University College. The son of Matthew Gray, Manager of the India Rubber, Gutta Percha, and Telegraph Works Company, Ltd., he entered the service of that Company in 1869. He later became Chief Electrician and in 1875 Engineer-in-Chief. The submarine-cable industry had by this time come through its initiatory period of romance and uncertainty and had settled down as a technical business involving for its successful accomplishment the combination of high scientific attainments and considerable commercial acumen. This combination Robert Kaye Gray possessed in a remarkable degree. In 1901 he became Managing Director of the Company and was in addition a Director of the following submarine cable companies:—Cuba Submarine Telegraph Co., Ltd., Spanish National Telegraph Co., Ltd. (*Chairman*), West African Telegraph Co., Ltd., and South American Cable Co., Ltd. (*Chairman*). With all the demands upon his attention, which his business pursuits made, he gave ungrudgingly of his time and his ripe experience to learned and other societies. He was a member of the Royal Institution, the Royal Society of Arts, the Institution of Civil Engineers, and the Institute of Metals. In all of these he took a lively interest, and in some he was an active worker, but it was to the Institution of Electrical Engineers that he gave his closest attention. He was elected an Associate in 1874, and a Member in 1877. He was first elected to the Council in 1894, served as Vice-President in 1895 and 1899, and in 1903 was elected President. It was in this year that the International Telegraph Conference was held in London, and the wisdom of the Institution in selecting so prominent a telegraph member as its premier officer was abundantly justified. The principal social function in connection with the Conference was a concert at the Albert Hall to which Mr. Gray invited all the members of the Institution to meet the delegates of the Congress. Excursions to Warwick Castle, Shakespeare's birthplace, and other historic localities, were organized and personally conducted by Mr. Gray, as well as visits to places of technical interest nearer London. The success of these excursions was remarked by all. Everything was foreseen and nothing happened that ought not to have happened. Mr. Gray organized these functions himself. He was the general, each department had its lieutenant, and the visitors, whilst appreciative of the results, were ignorant of the organization and the military precision by which such results were obtained. He was in charge of the foreign visits to Italy and St. Louis, ensuring for the members instructive and enjoyable trips, and for the Institution a representation in harmony with its position and traditions. To the Town Council of Colchester he presented in 1904 the picture by A. Ackland Hunt of Gilbert showing his experiments to Queen Elizabeth and her Court. As a mark of appreciation of his services his colleagues on the Council and past members presented him in 1906 with his portrait painted by Miss Beatrice Bright, daughter of the late Sir Charles Bright. A replica of the same portrait painted by the same artist was also presented to the Institution. In the year of his presidency the Institution sustained a very serious loss in the death of Mr. McMillan, the Secretary, whose untiring labours and single-minded devotion established a tradition which will long prevail. For some time Mr. Gray practically added the administrative duties of the Secretary to those of the President. He took exceptional care in the appointment of a new Secretary, organized a Committee for the purpose and took a leading part in its deliberations. It was found that the Articles of Association prevented the Institution making a suitable acknowledgment of Mr. McMillan's services by a pension or allowance to his widow and children, and Mr. Gray instituted that subscription from the members which made some amends for the lack of suitable acknowledgment from the Institution's funds. He represented the Institution on the governing bodies of the Imperial College of Science and Technology, and the National Physical Laboratory. For many years past Mr. Gray acted as Chairman of the Finance Committee of the Institution. It was a position for which he was admirably adapted. Sound in judgment, careful in details, he handled small things and great in a manner to attain the best results. He took great interest in the acquisition of the new building and its alteration, considered with much care the financial aspect, and was keenly appreciative of the satisfactory outcome. It has been well said of him that he was "the most beloved man in the broad community that centres upon the electrical and telegraph industry in this country," and it may perhaps with equal truth be said that the Institution of Electrical Engineers was by him the most beloved of the interests which occupied his time and thoughts. He cherished the objects of the Institution, was jealous of its honour and prestige, concerned that its influence should not be invoked for doubtful causes, proud of its progress, and solicitous for its continued welfare. He made no claims to oratory. He spoke with brevity, but with a sincerity and conviction which appealed with effect to every listener. Yet it was not as a speaker in a large gathering but when with "Friends in Council," as Chairman or Member of Committees, that his magnetism was most effective. Sincerity and unselfishness were his dominating characteristics, and thoughtful kindliness their constant manifestation. At the Albert Hall and other similar celebrations it was the Institution that was in the forefront and not Robert Gray; at Colchester he presented a picture on behalf of subscribers, but the preponderance (as is probable) of his own subscription was never considered. And it was the same in every action for the Institution. His was the word and the work of a man who sought the end and in the means thought not at all of himself. Esteemed as he was by his colleagues and every member of the staff the universal reflection must be that "take him for all in all we shall not look upon his like again." J. E. K.

JOHN WYKEHAM JACOMB-HOOD was born in 1859 and was educated at Tonbridge School and at the Crystal

Palace School of Engineering. He became a pupil to the then chief engineer to the London & South-Western Railway Company in 1875. From 1878 to 1887 he served in the capacity of assistant engineer to the Company, carrying out the construction of various new works. For the next eight years he was District Engineer in charge of the way and works in the London district, afterwards being transferred in 1895 to the Western district. In 1901 he became Chief Resident Engineer, a position that he held until his death, which took place suddenly at a meet of the Dulverton Hounds on the 6th March, 1914. He was responsible for the carrying out and maintenance of much of the electrical work of the Company, and took great interest in the question of electrification. In recent years his most important work was in connection with the enlargement and reconstruction of Waterloo Station. He was elected a Member of the Institution in 1904.

WALTER AMBROSE PEARSON died at New York on the 25th January, 1914, at the age of 44. After receiving a four years' training he entered the service, in 1890, of the West End Street Railway Company of Boston (Mass.) as Superintendent of Construction. He filled this post for three years, and then took charge of the power station of the Brooklyn Heights Railroad Company. In 1896 he was appointed Electrical Engineer to the Metropolitan Street Railway Company of New York—a post which he held for 10 years, until he became Chief Engineer to the Electrical Development Company which was engaged in constructional work at the Niagara Falls of transmission lines and transformer stations. Four years afterwards he became Assistant General Manager to the Rio de Janeiro Tramways, Light, and Power Company, but had to return to the United States in 1912 owing to ill-health. He was elected a Member of the Institution in 1909.

SIR WILLIAM HENRY PREECE, K.C.B., a Past President of the Institution, passed away on the 6th November, 1913, in his 80th year. He was one of those who had witnessed the entire growth of modern electrical engineering and who had himself all through his life taken the most active share in its development. Educated at King's College, London, of which he afterwards became a Fellow, and commencing his career under the late Mr. Edward Clark, he entered the service of the Electric and International Telegraph Company in 1854, becoming Superintendent of the Southern District in 1856. He also held concurrently the positions of Superintendent of Telegraphs on the London & South-Western Railway and Engineer of the Channel Islands Telegraph Company. He was likewise, prior to the foundation of Cooper's Hill College, selected by the Indian Government as the Telegraph Engineer, under whom entrants to the Indian Telegraph service received their practical training, and some 60 or 70 of these gentlemen passed through his hands. From the earliest days of electrical engineering, and during the whole of his career, he was always in the forefront in all new extensions of the range of the science, and apart from his own inventions, many useful developments were helped materially by his forceful advocacy. During his period of office as Superintendent of Telegraphs on the London & South-Western Railway, he invented his method of signalling the movements of trains on railways by the introduction of miniature reproductions of the outdoor signals, worked electrically from the distant cabins, together with many other devices to secure the safety of railway working, and he helped largely in the general adoption of the block system for railways in the United Kingdom. When in 1870 the various telegraph companies, about 30 in number, which were engaged in the business of transmitting telegrams in this country were transferred to the State, Mr. Preece, as he then was, became a Divisional Engineer under the Post Office. In 1877 he became the Electrician, and from 1892 to 1899, when he retired, he carried out the duties of Engineer-in-Chief to the Post Office. He was made a C.B. in 1894, and became a K.C.B. five years later. He materially improved the telegraph system in this country, devoting his attention primarily to methods of high speed and multiplex systems of working, whereby he so increased the carrying capacity of existing wires as to provide for the enormous increase of traffic arising from the reduction of rates with only a reasonable increase of external plant. Telephones, electric lighting, traction, and all other modern applications of electricity equally engaged his attention. He was a prolific writer, an admirable lecturer, and he acquired a world-wide reputation as one of the foremost electrical engineers of the age. On his retirement from the Post Office Sir William Preece entered into partnership with two of his sons and Major Philip Cardew as consulting engineers in Westminster. Latterly Sir William had resided at Carnarvon, but he still continued to take the warmest interest in the welfare of the Institution and missed no opportunity of extending its interest and prestige.

Sir William had acted as a member of the Council of the Institution almost from its inception. He served as Vice-President in the years 1877–1879, and was elected President in 1880 and again in 1893. He contributed innumerable papers to the Proceedings of the Institution as he did also to those of the Institution of Civil Engineers, the British Association, the Royal Society of Arts, and the Physical Society. He acted as the representative of the Institution at the opening of the United Engineering Societies' building in New York and at the Franklin bicentenary celebration. He was President of the Institution of Civil Engineers in 1898. J. G.

ALFRED RICHMOND SILLAR, born on the 22nd April, 1871, was educated at Shrewsbury and at the City and Guilds Technical Institute, Finsbury. He served a two years' apprenticeship with the Electrical Engineering Corporation, and was then employed by Messrs. J. G. Statter & Co., first as an improver, and subsequently as outside foreman. In 1895 he became Outside Manager to Messrs. Foote & Milne, and a year later was appointed Resident Engineer to the Blackpool Winter Garden and Pavilion Company, where he had charge of what was at that time one of the largest private installations in this country. In 1899 he was appointed Resident Electrical Engineer at Colchester, and also supervised the construction of the electric tramways in that town. He left Colchester in 1911 on being appointed Chief Engineer to the Chinese Chartered Electric Lighting Company of Pekin, which position he occupied until his death on the

20th May, 1914. He joined the Institution in 1892 as a Student, and was elected an Associate in 1895, an Associate Member in 1901, and a Member in 1904.

SIR JOSEPH WILSON SWAN, a Past President and an Honorary Member of the Institution, died on 27th May, 1914, at the age of 85. Most people identify Swan with the incandescent lamp, and forget what a prolific inventor he was in other directions. Naturally, the Institution is more interested in his electrical work, but his other inventions must not be forgotten. He was essentially a careful and painstaking observer, and an indefatigable worker with infinite resource in tackling the difficulties that come up in the development of new processes. His work in photography includes the perfection of the dry plate. It is true that there were dry plates of a sort before he took the matter up, but we owe the modern rapid gelatino-bromide plate to him. The application of the same emulsion to paper, producing bromide paper, is also his invention. Though not the actual inventor of the carbon, or Autotype, process, he is entitled to the credit for producing the first practicable process. From it was evolved the present-day photogravure process, and this also gave rise to a sort of intaglio printing on power presses, for newspaper work, the ink being thicker where the hollow is deep, with the result that when dry it is darker. By this means all the shades or tones of the original are obtained, so that the impressions are practically duplicates of the original carbon print, showing all the gradations with no visible grain due to any screen. He also applied the screen to reproducing half tones in relief blocks with ordinary ink, and was thus a pioneer in what is generically called process work. Mr. Swan, as he then was, entered into partnership with Mr. Mawson when quite a young man. Mr. Mawson was killed by the explosion of some nitro-glycerine which had been found in Newcastle. This was in the time of the "Fenians," and Mr. Mawson had to superintend the destruction of the nitro-glycerine, which was to be run into the earth on the Town Moor. There was no means of knowing what caused the explosion, as there were no survivors; but it is supposed that some of the nitro-glycerine was frozen, and that a workman tried to help it out with a spade. Mr. Swan thus had the whole responsibility of the firm on his own shoulders. Part became "Mawson, Swan & Morgan" and devoted its attention to books, stationery, and so on; but "Mawson & Swan" became the leading house in the North for chemicals and scientific apparatus, and especially for photographic goods. In wet-plate days "Mawson's Collodion" was in universal demand, and even now, owing to its employment for photo-mechanical processes, it has a very large sale. Then came the Swan dry plates with the ferrous-oxalate developer, and these still enjoy wide popularity. The firm also made ink and yeast.

The incandescent lamp interests us more. There has been much discussion as to whether Swan or Edison invented the incandescent lamp. In fact, invention practically always consists in outstripping competitors; but in this case Edison and Swan were hardly racing, as they were on different roads. In 1878 there was a great exhibition in Paris, and the Jablochkoff and some other arc lights were shown. The great problem of the day was what was called "The Subdivision of the Electric Light." The only dynamo in common use was the Gramme, which was series wound. Dynamo design was not understood then, and these machines though series wound had drooping characteristics, and worked one arc each. It is very difficult for modern engineers to carry their minds back to those days. The Jablochkoff was one solution of the subdivision problem, as one dynamo worked several lamps. The Brush series system of 1878 was another. Very advanced electrical engineers of those days could see the difference between the series and the parallel arrangement of lamps. Edison fully realized that parallel distribution must be used for lighting a town, and it was possible only with what was then a very high pressure, about 100 volts, and a small current for each lamp. He also realized that carbon is permanent in a vacuum; and he took out the classical patent for a lamp with a carbon filament of high resistance in a vacuum. The Edison invention was really the true solution of the problem of the subdivision of electric light. Edison had been working at a platinum lamp for some years, and though he took out this patent, he apparently went on working at platinum and took up the carbon lamp seriously somewhat later. Swan, on the other hand, does not seem to have concerned himself at first with questions of distribution; he tackled the problem of making a practical carbon incandescent lamp. He began with a low-pressure lamp, having a small rod of carbon, and then when he had found that the material carbon was right, he turned his attention to making it of high enough resistance to be useful for parallel running. It is very hard for us to realize the difficulties of working out such an invention. He was essentially a practical chemist with an extraordinary knowledge of commercial chemistry, but he was not a trained electrician, nor was he a physicist. He found an enthusiastic collaborator in Mr. C. H. Stearn, who had already done work with the Sprengel pump; and while Mr. Swan worked at the preparation of the filaments in Newcastle, Mr. Stearn, and his able assistant, Mr. F. Topham, did the exhausting. In those days there were no good measuring instruments. There were electrodynamometers, which were not direct reading, and not very accurate; but these instruments were practically useless for lamp work, as if the current instrument was between the voltmeter terminals the pressure read was too high, and if the current instrument was outside it included the voltmeter current, and people in those days did not think of such things. Moreover, the generator was always a series-wound dynamo driven by a gas-engine with a "hit and miss" governor and a rise of pressure at every explosion. Swan first proved that carbon was suitable, and then set to work to find out a practical way of making fine carbon threads. He worked out the parchmentized cotton process, and later a method of squirting nitro-cellulose and reducing the thread with ammonium sulphide. The squirting process is now in universal use for carbon lamps, a solution of cellulose in zinc chloride, or "viscose," being used. In the Inventions Exhibition of 1885 he showed a beautiful lace handkerchief made entirely of squirted cellulose. This was, however, subsequent to Chardonnet's first patents. The method of mounting the filament on the leading-in wires by short-circuiting the joints under some such liquid as benzol, or benzol and aniline, was

another great advance. There was great difficulty in mounting a carbon satisfactorily. He was also one of the pioneers in the development of the secondary battery. About 1880 Planté had called attention to the possibilities of the secondary battery. He used plain lead plates and "formed" them. Faure had brought out a pasted plate, but it was not satisfactory. Swan and J. S. Sellon were early workers on lead plates with large surfaces so that they could be formed, and on plates designed to hold an applied coating and to keep in good contact with it. The last of Swan's important inventions is the addition of small quantities of such bodies as glue or gelatine to a copper deposition bath. This, under proper conditions, enables the deposit to be made very rapidly, and is thus of great commercial importance. Generally speaking, an inventor—even a great inventor—makes only one invention in his life-time. Swan, on the other hand, seems to have been perfecting one invention after another during the greater part of a long life; and it is when all his work is considered that one gets an idea of the real greatness of the man. He was a great judge of character, and in most cases chose his assistants and co-workers well; his great ability, and his kindly character and great natural goodness, attached his subordinates to him with great affection and loyalty. He was elected a Member of the Institution in 1881, was President in 1898–1899, and was made an Honorary Member in 1900. He was also a Fellow of the Royal Society, a Chevalier of the Legion of Honour, the first President of the Faraday Society—apparently being chosen as the most eminent and best example of the combination of the knowledge of science and of its applications—President of the Society of Chemical Industry, and the recipient of the Albert Medal of the Royal Society of Arts. He was knighted in 1904. After a long and extraordinarily useful life he died full of honours, all well deserved. J. S.

WILLIAM ROWAN WILSON was born at Partick, Glasgow, on the 14th February, 1872, and was educated at Glasgow Academy and at Glasgow University. After taking his B.Sc. degree he assisted Lord Kelvin for some time. He then entered the Glasgow Corporation Electricity Department, and from there went to Messrs. John Fleming & Co., Bombay, the Indian house of Messrs. Thomas Wilson & Co. of London. He subsequently became Manager of the New Edgerton Woollen Mills, Dhariwall, India, and later was fitting up the electric light installation for Simla when he was appointed Director of Industries at Cawnpore. He had to retire owing to ill-health, and he died at Glasgow on the 9th December, 1913, at the age of 41. He was elected an Associate of the Institution in 1896 and a Member in 1898.

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EXPLANATION OF ABBREVIATIONS.

(P) indicates a reference to the general title or subject of a paper or address.

(p) indicates a reference to a subject dealt with in a paper or address of which the title is not quoted.

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(d) indicates a reference to a subject dealt with in a discussion on a paper or address of which the general title is not quoted.

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